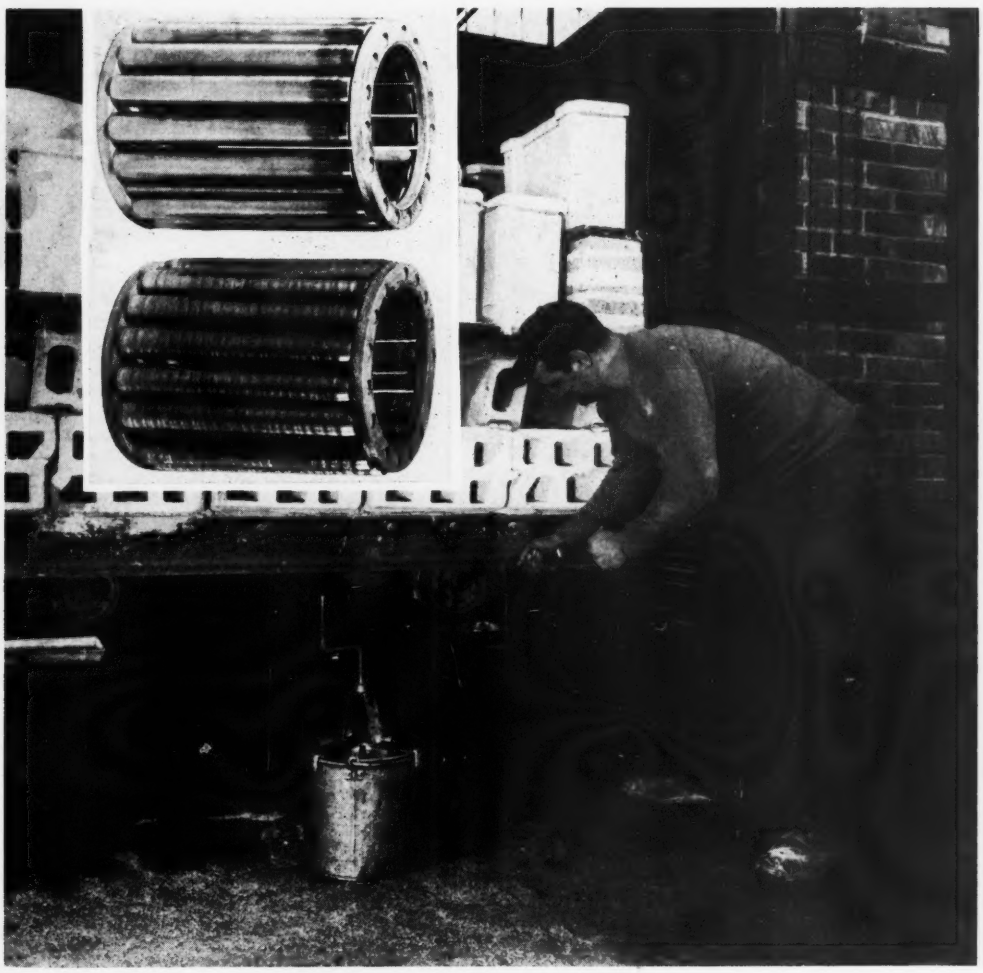
Vol. 12, No. 6 November-December, 1956

LUBRICATION ENGINEERING

RESEARCH APPLICATION EDUCATION MAINTENANCE



Kiln-Car Roller Bearing Lubrication
(Cover Story, p. 359)

JOURNAL OF THE AMERICAN SOCIETY OF LUBRICATION ENGINEERS

1956 Subject & Author Indexes, p. 423

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Members: Members shall be persons not less than 24 years of age who: (1) are engaged in research and instruction at technical schools, universities, and various publicly and privately supported institutions in the field of lubrication; or (2) have occupied recognized positions as lubrication engineers for a period of three or more (not necessarily consecutive) years prior to date of admission, involving the responsibilty for or supervision of the development, selection, field use and application of lubricants as differentiated from other activities; or (3) are indirectly concerned with the field of lubrication, but possessing other qualifications of experience, knowledge, and accomplishment, and have manifested a particular interest in the purposes and welfare of the Society to the extent that their membership would be a valuable contribution to the successful functioning of its activities. Fee $15.00.

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LUBRICATION ENGINEERING

RESEARCH APPLICATION EDUCATION MAINTENANCE

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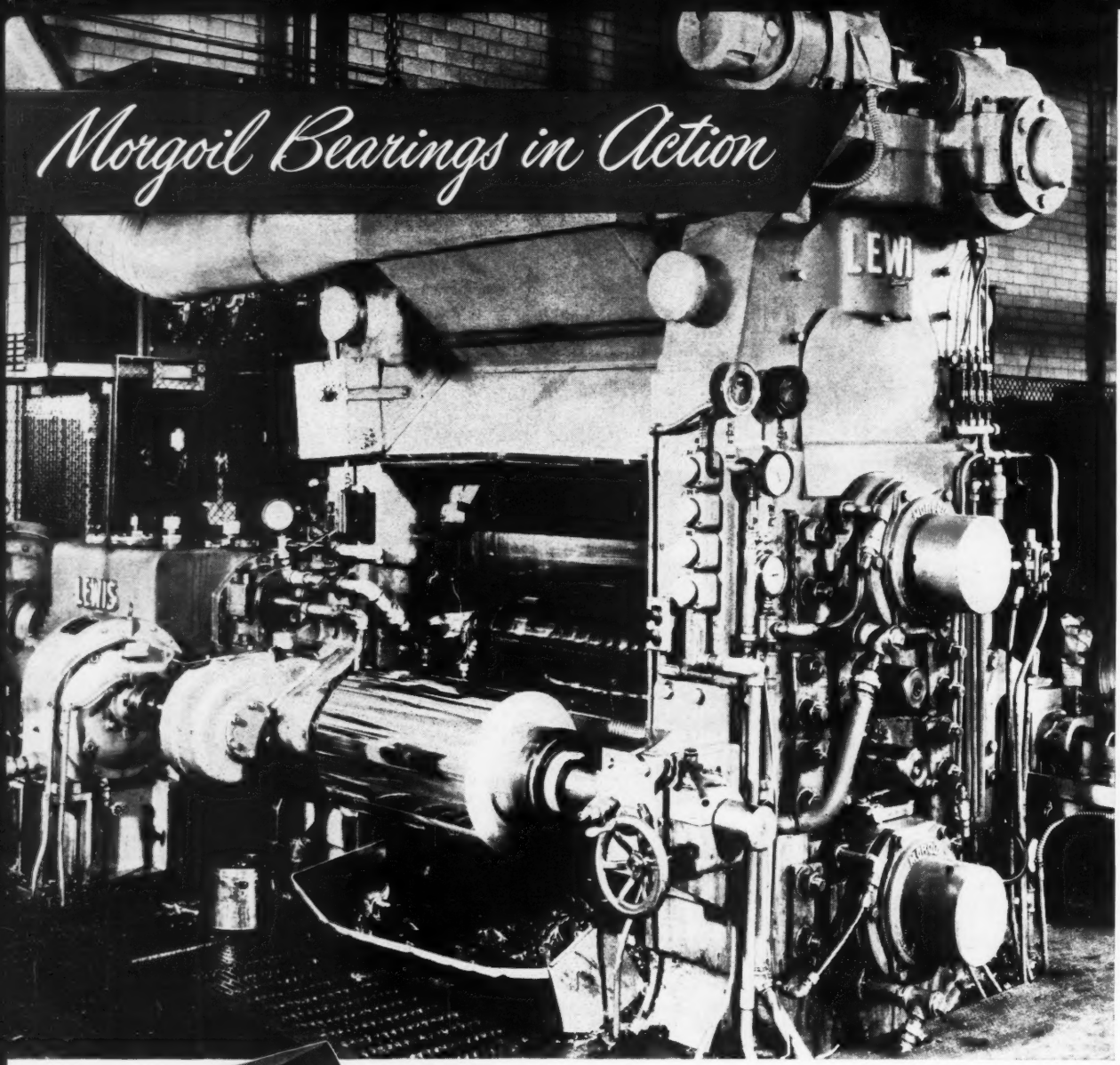

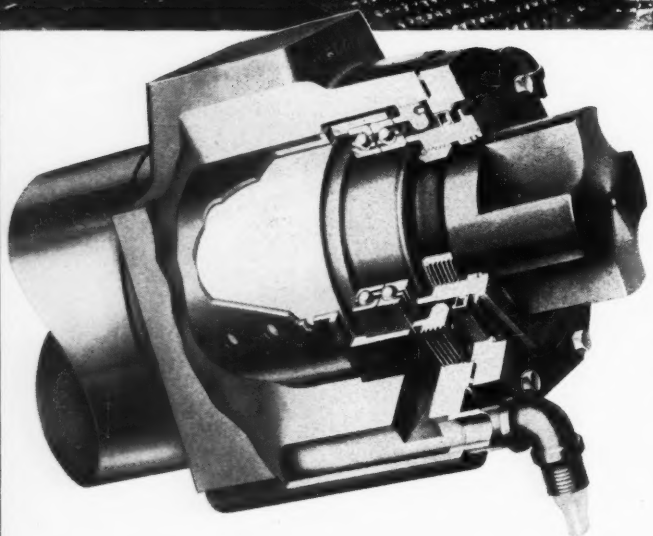

The 18″-72″ MORGOILS on the 9″ and 21″ x 44″ Aluminum Foil Mill at Cochran Foil Co. pictured above make it easier to produce a quality product at high speed. Foil as thin as .00025 of an inch is rolled at speeds approaching 4000 feet per minute on MORGOIL-equipped mills. MORGOIL BEARINGS give you freedom from wear and fatigue and permit operation at high speeds with remarkable long bearing life.

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THE SIGHT GLASS

Highlights of Articles Scheduled for Coming Issues!

Symposium on Industrial Dermatosis

One of the Highlights of the 10th Annual Meeting of ASLE in Chicago on April 13, 1955, was a panel discussion devoted to Skin Diseases Due to Cutting Oils and Lubricants. The panel, organized by Dr. Clarence Livingood, Physician-in-Charge, Division of Dermatology, Henry Ford Hospital, Detroit, was composed of specialists and experts in their respective fields. Through the efforts of Dr. Livingood, the individual panel members were prevailed upon to prepare their contributions in a form suitable for publication in the journal. The resulting papers will be presented as a series beginning in January and continuing for six issues. Don't miss this important treatment on one of the Lubrication Engineer's most provocative problems.

Lubrication of Friction Drives

Friction drives are frequently employed when continuous variation in the speed ratio of coupled shafts is required. Power transmitting elements are heavily loaded to obtain the high frictional forces necessary and lubricants possessing a high coefficient of friction are desirable. A test apparatus is described which involves two rotating balls pressed together so that the frictional behavior can be measured in the region of speeds about the nominal rolling condition. The role played by the temperature coefficient of viscosity of the lubricant in determining the efficiency of the frictional drive is discussed.

Use of an Automatic Viscometer for the Study of Lubricant Flow

Knowledge of the flow properties of lubricants is essential for an understanding of many lubricant problems. In fluid film bearing lubrication, the coefficient of friction in the bearing is dependent upon flow properties. In the transporting of lubricants, in manufacture, feeding of bearings, and various industrial applications, the flow properties are most important for determining pipe-line design requirements. Many lubricants, such as greases, are non-Newtonian and time-dependent materials. Flow behavior of such material can be studied from curves recorded directly with a rotational concentric-cylinder viscometer, which has been designed so that the flow conditions of shear rate and time can be controlled automatically. Flow curves obtained under controlled flow conditions are presented and analyzed for a diester and two greases to show the effects of the flow properties and variations with time, rate of shear, and temperature on bearing lubrication, and on the transport of lubricants in pipe lines.

The Assessment of Automotive Bearing Performance from Field Tests

Conditions under which bearings are subjected during service are practically impossible to simulate in the laboratory. Data from general service experience, however, is difficult to obtain and frequently unreliable. By controlled service tests of bearings it is possible to bridge the gap in bearing examination techniques and determine statistical significance for observed differences in the materials used and the test designs.

Grinding Temperatures

Tool tip temperatures are of interest to the engineer dealing with metal cutting operations since cutting tool life is directly influenced by these temperatures. Surface temperature is of major interest with regard to crack information and surface damage. Measurement techniques with a photoconducting lead sulfide cell and an oscilloscope are used to experimentally examine freshly ground surface temperatures. The effects of both water- and oil-based fluids on temperature are described.

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LUBRICATION ENGINEERING

RESEARCH APPLICATION EDUCATION MAINTENANCE

Volume 12, No. 6
November-December 1956

Stagnant Manpower

Fluid power is one of the most active subjects of discussion in power transmission engineering circles today. Ever since the concept of fluids in motion was set forth by Pascal more than three hundred years ago and applied by Joseph Bramah in the late 18th century to the first hydraulic press, the application of hydraulic power first by water, then by petroleum oils and non-flammable fluids has been distinctive for its versatility. Obviously there is nothing static about this; engineering design is continually perfecting means for more advanced and economical applications.

In contrast, however, the very people who have to do with this advancement as well as all other advancements in engineering today, are subject, as they become older to stagnation tomorrow. That boon to the oldster — retirement with pension at 65 or some other age, is one of the greatest contributors to stagnant manpower. This holds true particularly in engineering where years of technical know-how suddenly are shelved by organizations who have invested so much in developing this very know-how in the individual.

It is perfectly true that physical condition must be considered. Some at retirement age certainly warrant this blessing of ease with income; others, however, are the mental and physical equals of people ten to fifteen years their junior. So an arbitrary rule of thumb is out of the question. Instead, the question should be how to evaluate the latent ability of the "still useful" individual and use this ability for community benefit. Quite naturally companies cannot retain some and let others go. The retirement and pension plans must hold for all, regardless of status. But the community can cash in on this latent know-how particularly with regard to technical people, i.e., *by enabling them to impart this know-how to others by teaching.*

It will be contended, of course, that relatively few technical people have had teaching training. Don't forget, however, that many are accustomed to public speaking, and often before a not too sympathetic audience of their peers. Granted that this is true, how should we go about preventing this manpower from stagnating?

Probably the most effectual procedure would be to continue to let the retired technical people know that they are still needed and are factors in engineering manpower utilization. Unfortunately this is too often overlooked.

What then? Well, here is where the community fits in. John Doe normally cannot be immediately invited to join the teaching staff of his Alma Mater; colleges, too, have retirement plans. But in many states there is urgent need for additional instructors in basic sciences and mathematics in the secondary school systems. Were the manufacturing companies to advise these State Boards of Education of the names, addresses and technical capabilities of prospective retirees it is fair to presume that a reasonable percentage of these oldsters would gladly postpone fishing and gardening for a few years, to take refresher courses in mathematics, physics and chemistry so as to be able to join the teaching personnel in their neighborhood secondary schools where there is need for their services, either part time or full time.

The trouble seems to be today, "out of sight, out of mind." Life extension is not much use if the incentive to be useful is lacking. Industry can play a major part by remembering that their retirees still exist, and telling educators of their latent teaching possibilities. And what an inspiring incentive to the embryo scientist or production engineer to receive instruction in a practical manner from those who have played an important part in our modern industrial and scientific developments.

A. F. Brewer
Consulting Editor

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Here's a multi-purpose, lithium-base grease that pumps freely at below-zero cold and at 270° F heat. INLUCITE 21's all-weather pumpability and amazing mechanical stability mean greater protection in wheel bearings, water pumps, universal joints, shackles and other grease-lubricated bearings. For maximum trouble-free operation, be sure your choice is INLUCITE 21, the lithium-base, multi-purpose grease with maximum temperature range.

won't wash out

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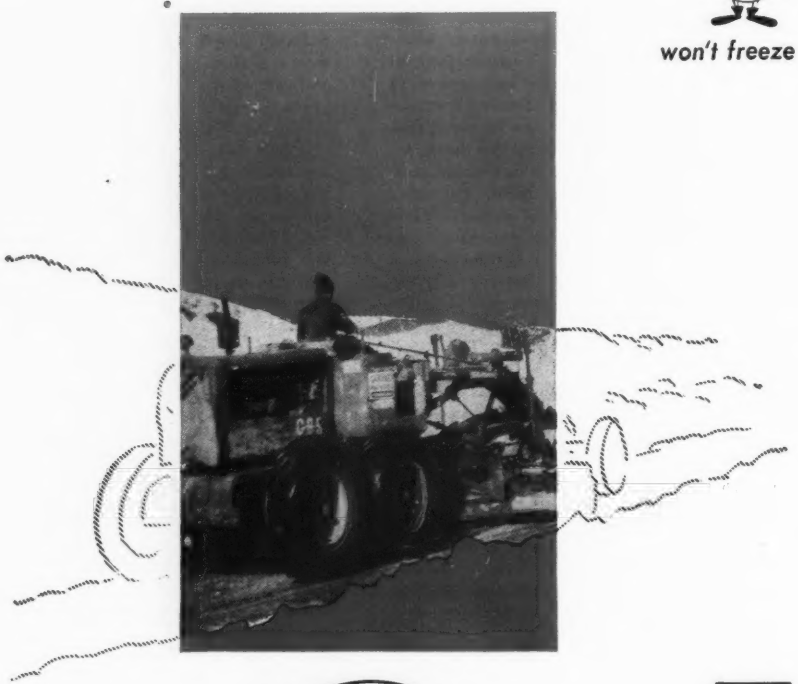

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Lubrication in the News

Transmission Fluid Certification. If the transmission fluid you buy for your automobile bears the label "AQ-ATF," you can be certain it will give first class performance. The letters stand for "Armour Qualification — Automatic Transmission Fluid." The symbol represents assurance that continued use of the fluid will protect the inner mechanism of your car's automatic transmission.

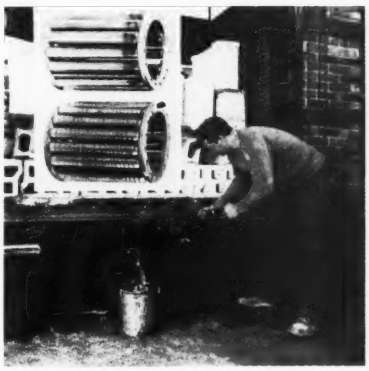
The "Armour" refers to Armour Research Foundation of the Illinois Institute of Technology, Chicago, which acts as an independent investigating agency in evaluating the formulas submitted by petroleum refiners. The program, which was begun seven years ago, now includes "Type A" transmission fluids marketed under more than 400 trade names.

This labeling plan resulted from the first automatic transmission introduced by General Motors Corp. It was found that a special fluid was necessary to function as a hydraulic power-transmission medium, hydraulic control fluid, heat-transfer medium, clutch fluid, and a gear and bearing lubricant. "Even the highest quality lubricants on the market at that time were not suited for this use," according to H. R. Barton, supervisor of engines, fuels, and lubricants at ARF.

To measure up to these requirements, GM developed Automatic Transmission Fluid, Type A. Because successful performance of the transmission depended upon continued use of the proper fluid, and because few petroleum refiners at the time produced such a product, GM set up a qualification system to provide widespread marketing of the fluid under various trade names. In 1949, GM called on ARF to act as the independent investigating agency in qualifying formulas submitted by petroleum refiners.

Fluids submitted to the Foundation are given 18 different tests on durability, miscibility, viscosity, fire point, pour point, rust preventions, and others. If the formula passes, it is sent to GM for other performance tests. After that, it is submitted to a GM technical committee. Barton states, "Because of the dependability of the fluid and qualification method, other automobile manufacturers also recommend use of Type A as the best protection for their automatic transmissions."

Cover Story



Kiln-Car Roller Bearing Lubrication. The photograph on the front cover of this issue shows a kiln-car roller bearing being lubricated with a hand-pressure gun (the overflow is caught in pans and reclaimed); the insert depicts two roller bearings from the same kiln car—the top bearing was lubricated with a mixture of synthetic lubricant and graphite, the lower bearing was lubricated with a conventional oil and graphite.

When lubrication problems are considered from the standpoint of operating conditions, the most difficult to solve with conventional lubricants are those that involve unusually high temperatures. In firing ceramic ware, however, high temperatures are the usual thing — kiln temperatures top 2000° F. And, temperatures reach 500° F. at the wheel bearings on the cars that carry the ware slowly, but at a constant speed, through the kilns.

With a certain manufacturer of ceramic ware for bathrooms, kiln-car lubrication was a constant and costly problem. Regular petroleum oils mixed with graphite broke down and clogged the bearings, making it difficult to roll the cars around the plant. Often, it took seven men with crowbars to budge them. When complete breakdowns occurred, the cars had to be jacked up, new bearings substituted, and the carbonized mass actually drilled out of the old bearings. These troubles slowed down production and resulted in much lost time until synthetic lubricants with graphite were tried.

Because the decomposition products of these lubricants are volatile, they do not clog the bearings. (Submitted by Carbide & Carbon Chemicals Co., manufacturer of UCON synthetic lubricants, and reprinted in part from their March '55 issue of "Chemical Progress.")

Coming Events

DECEMBER 10-12, American Nuclear Society (Winter Meeting), Washington, D. C.

10-12, Eastern Joint Computer Conference (sponsored by IRE, AIEE & ACM), Hotel New Yorker, N. Y., N. Y.

26-31, American Association for the Advancement of Science (Annual Meeting), Statler Hotel, N. Y., N. Y.

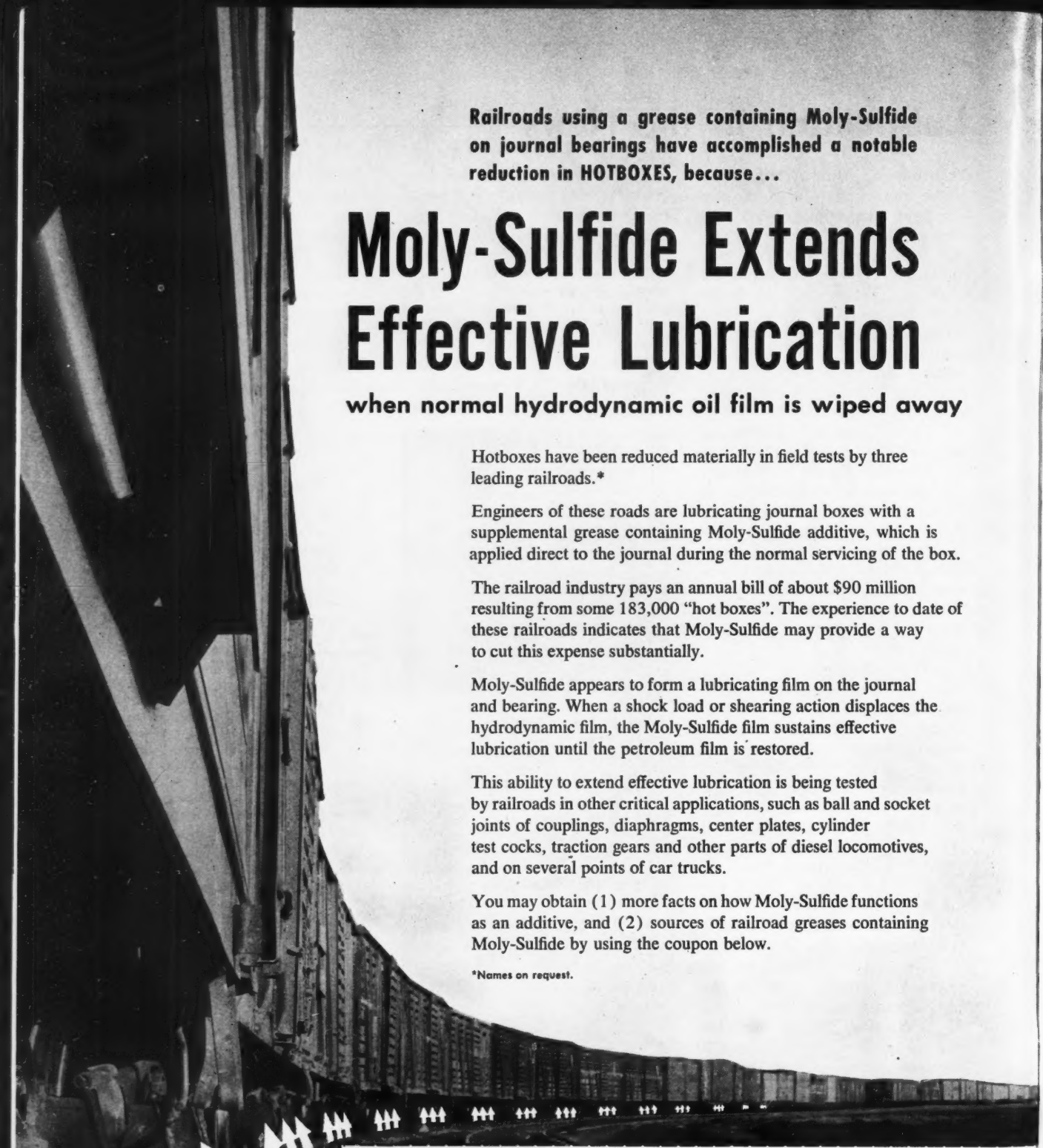
27-29, American Physical Society, Monterey, Calif.

29, Mathematical Association of America (Annual Meeting), University of Rochester, Rochester, N. Y.

29-30, American Chemical Society, Division of Industrial & Engineering Chemistry (Christmas Symposium), Princeton University, Princeton, N. J.

JANUARY 28-31, 1957, Plant Maintenance & Engineering Show, Public Auditorium, Cleveland, Ohio.

APRIL 15-17, 1957, American Society of Lubrication Engineers (12th Annual Meeting & Exhibit), Sheraton-Cadillac Hotel, Detroit, Mich.



Railroads using a grease containing Moly-Sulfide on journal bearings have accomplished a notable reduction in HOTBOXES, because...

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when normal hydrodynamic oil film is wiped away

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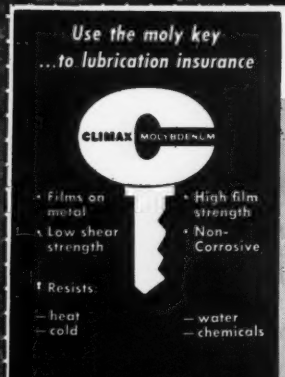
Moly-Sulfide appears to form a lubricating film on the journal and bearing. When a shock load or shearing action displaces the hydrodynamic film, the Moly-Sulfide film sustains effective lubrication until the petroleum film is restored.

This ability to extend effective lubrication is being tested by railroads in other critical applications, such as ball and socket joints of couplings, diaphragms, center plates, cylinder test cocks, traction gears and other parts of diesel locomotives, and on several points of car trucks.

You may obtain (1) more facts on how Moly-Sulfide functions as an additive, and (2) sources of railroad greases containing Moly-Sulfide by using the coupon below.

*Names on request.



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- ☐ "Moly-Sulfide Specification and Properties"

Lists of Sources for

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- ☐ Chassis Greases

Sample — One-ounce tube of Moly-Sulfide ☐

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Personals

F. W. Evans

C. P. Graham

D. G. Reed

J. T. Vollbrecht

W. Simmons (ASLE Kansas City Section) has been promoted to Sales Manager of Southwest Grease & Oil Co., Wichita, Kan.

Pate Oil Co., Milwaukee, Wis., has announced the appointments of **W. A. Alexandroff** and **M. Bates** (ASLE Milwaukee Section members) as Manager — Industrial Sales Div., and Sales Engineer for the Fox River Valley territory, respectively; and D. Hummer as Sales Engineer for the Racine and Kenosha territory.

M. J. Connolly, Jr., has been named Assistant Sales Manager — Headquarters Sales, of the Bound Brook Oil-Less Bearing Co., Bound Brook, N. J.

C. A. Wallace, Manager of the Industrial Filtration Div. of U. S. Hoffman Machinery Corp., New York, N. Y., has been awarded an especially-designed gold pin to mark 25 years of service with the company.

The Texas Co., New York, N. Y., has announced the appointments of J. H. Moran as Director of Trade Relations, and D. Hendrix as Manager — Marine Sales Division.

B. K. Moores has been appointed Director of Industrial Marketing for The Lehigh Chemical Corp., Chestertown, Md.

Inter-State Oil Co., Kansas City, Kan., manufacturer and distributor of a full line of lubricants for 69 years, has announced the sale of the entire company, including all trade names and assets, to certain key employees effective October 1, 1956. Newly-elected officers include: **L. W. Beal** and **G. Asplund** (ASLE Kansas City Section members) as President & General Manager, and Vice-President & General Sales Manager, respectively; F. C. Rayburn as Secretary, and E. Gray as Treasurer.

J. T. Vollbrecht, president of Energy Control Corp. (New York, Baltimore, and Philadelphia), was elected national President of the Instrument Society of America for 1956-57, succeeding R. T. Sheen, president of the Milton Roy Company.

The Aro Equipment Corp., Bryan, Ohio, has announced the promotions of **D. G. Reed** (ASLE Ft. Wayne Section) to Manager — Industrial Sales, and R. E. Sprow to Manager — Automotive Sales, both for the Lubricating Equipment Div.; and C. P. Graham to Chief Engineer in charge of all engineering and research activities covering the company's industrial air tools, lubricating equipment, and aircraft products.

F. W. Evans has been appointed Assistant to the President (J. E. Shields) of Surpass Petrochemicals Ltd., Scarboro, Canada, and Alox Corp. of Niagara Falls, N. Y. Mr. Evans' duties will include the correlation of an intensified program of research and development at both companies, as well as supervision of all phases of engineering, production, sales, and general plant operations at Surpass.

Obituary: **A. J. Boyer** (ASLE Philadelphia Section), E. F. Houghton & Co., Philadelphia, Pa., August 20.

NEW ASLE JEWELRY

Lapel pins and tie clasps featuring the new insignia, gold detail on a blue background with white lettering, are now available through the local Sections or National Office. The lapel pin is also being offered as a free premium to all members getting a new member. *Details are available through the Sections or National Headquarters.*

Lapel Pin **$1.50**
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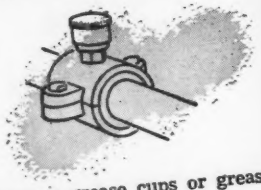
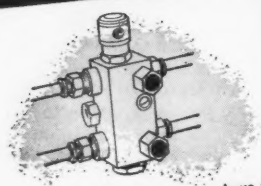
Meets **toughest** lubrication requirements!

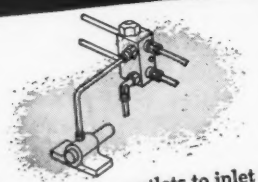
Can be designed into any machine, in 4 easy steps



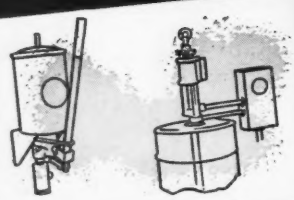
1. Remove grease cups or grease fittings.



2. Connect each valve in system to its two lubricant supply lines.



3. Connect valve outlets to inlet of bearings. (Each valve serves two bearings.)

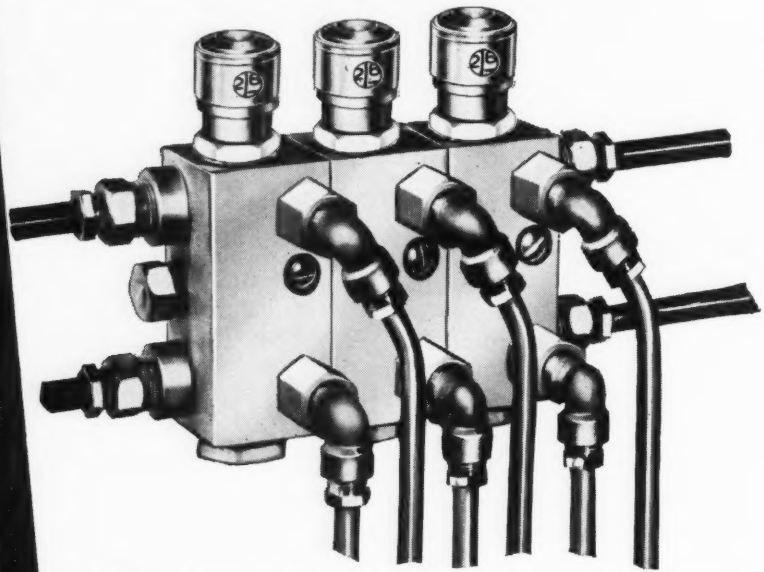


4. Provide central pump for supplying lubricant to system.

ALEMITE

Accumatic®

CENTRALIZED AUTOMATIC LUBRICATION



Alemite Type II Accumatic Valves meet big-volume requirements . . . handle difficult multiple-bearing lubrication under all conditions. Fully sealed for *clean* lubrication of power shovels, cement kilns, conveyors – any outdoor or indoor installation. Operate whether completely immersed in fluid . . . covered by dirt or grit . . . or protected by anti-corrosive paint. For fluid oil or light grease. Four sizes, delivering from .050 to .500 cu. in. of lubricant. Fully hydraulic – no springs to adjust or replace.

Now available with Lubrication Recording Cycle Counter – for a fully automatic record of bearing lubrication!

FACTORY-TESTED – FIELD-PROVED!

Tests show no appreciable variation in the amount of lubricant discharged after 73,312 cycles – equal to *122 years of twice-a-day service!*

ALEMITE

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A Product of STEWART-WARNER CORPORATION

Alemite Accumatic Type II Offers All These Advantages!

- Prevents application of wrong lubricant.
- Seals completely against dirt, grit, water.
- No parts are neglected – lubricates inaccessible and dangerous bearings.
- Eliminates product spoilage due to over-lubrication.
- Eliminates point-by-point lubrication methods – services all bearings in one operation.
- Delivers exact amount of lubricant to bearing.

FREE!

Alemite, Dept. P-126
1850 Diversey Parkway, Chicago 14, Illinois

Please send me my free copy of the Alemite Accumatic Catalog.

Name_____

Company_____

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A PRODUCT OF SW STEWART WARNER

Section News

BALTIMORE, September meeting. Dr. J. O. McLean (ASLE Vice-President at Large), Reynolds Metals Co., presented a paper entitled "Purification of Aluminum Cold Rolling Oils."

October. "Mechanical Seals," by J. J. O'Keefe, Bethlehem Steel Co.

November. Pre-Holiday Ladies' Night (Submitted by C. J. Devries, Sec'y.)

CENTRAL OHIO, September. Organization of ASLE Central Ohio Section, and Election of Officers (see ASLE Directory). (Submitted by H. W. Irion, Chrmn.)

CHICAGO, October meeting. S. D. Craine, Jones Machinery Div. of Hewitt-Robins Inc., presented a paper entitled "Gear Lubrication." (Mr. Craine, a Past Chairman of the ASLE National Technical Committee on Gears & Gear Lubrication, and a present member of the ASLE Handbook Advisory Committee, has presented Gear Lectures at the ASLE-sponsored lubrication courses at Georgia Tech., Massachusetts Institute of Tech., Northwestern Univ., and the Univ. of Pittsburgh.)

November. "Soluble Cutting Oils," by G. A. Cairns, Macco Products Co.

1957 Program Schedule: Jan. 17, "Rust Preventives," by E. J. Colerick, Shell Oil Co.; Feb. 21, Ladies' Night; Mar. 21, "Filtration of Fuels & Lubricants used in Industrial Engines," by J. R. McCoy, Chemical Filters Corp.; Apr. 18, "Additives," by G. E. Evans, Penola Oil Co.; May 16, "Lubricating Greases & Extreme-Pressure Properties," by R. A. Swenson, Standard Oil Co. (Ind.); June 20, Annual Golf Party. (Submitted by E. W. Drummond, Sec'y-Treas.)

CLEVELAND, September. Annual Golf Party at Columbia Hills Country Club.

October. "Practical Aspects of Steel Mill Lubrication," by G. H. Davis, Shell Oil Co. (Submitted by G. L. Smith, Sec'y.)

DULUTH/IRON RANGE, August. Organization of ASLE Duluth/Iron Range Section, and Election of Officers (see ASLE Directory).

September. (Joint meeting with ASLE Twin Cities Section). J. Hoolihan, Industrial Lubricants Co., presented a paper entitled "Open Gears" at the evening session held in Duluth; the following morning, Reserve Iron Mining Co. served as host for a conducted tour of their new Taconite Plant in Silver Bay. (Submitted by C. D. Johnson, Sec'y.)

LOS ANGELES, October meeting. D. P. Thomas, Columbia-Geneva Steel Div. of the U. S. Steel Corp., discussed "The Lubrication Engineer's Manual" published by U. S. Steel's Lubricants Testing Lab., National Tube Div.

November. "Lubrication in the Presence of Nuclear Radiation," by R. O. Bolt & J. G. Carroll, California Research Corp.

1957 Program Schedule (tentative): Jan. 9, "The Lubrication Requirements of Refrigeration Equipment," by a representative of The Texas Co.; Feb. 13, "The Effect of Lubricants & Hydraulic Fluids on Hoses, O-Rings, Etc.;" Mar. 13, "Problems with the Lubrication & Maintenance of Sleeve Bearings," by a representative of the Federal Mogul Corp.; Apr. 10, "Fundamentals, General Recommendations, & Laboratory Evaluation of Cutting Fluids," by Dr. L. H. Sudholz, Socony Mobil Oil Co., Inc.; May 8, "Technical Writing Tips," by J. L. Kent, Consolidated Electrodynamics Corp.; June 12, Annual Field Trip. (Submitted by R. Wheeler, Program Chrmn.)

MILWAUKEE, September meeting. H. B. Carpetner, Esso Standard Oil Co., presented a paper entitled "Petroleum-Base Rust Preventives."

October. Panel discussion on "Lubricating Greases," with W. Elliott, Allis Chalmers Mfg. Co., as Moderator, followed by a movie entitled "Petroleum."

November. "Small Shop Lubrication," by D. Johnson, Standard Oil Co. (Ind.).

December. Annual Christmas Party.

1957 Program Schedule: Jan. 17, "Lubrication in Food Processing & Allied Industries," J. Bear (Program Chrmn.), Shell Oil Co.; Feb. 21, Joint meeting with E.S.M.; Mar. 21, Panel discussion on "Conveyor & Chain Lubrication," with R. Wickman, Hotpoint Mfg. Co., as Moderator; Apr. 18, "Oil Filtration in the Modern Plant," R. Bussard (Program Chrmn.), The Ladish Co.; May 18, Social meeting and Ladies' Night, under the direction of R. Klumb, Jos. Schlitz Brewing Co. (Submitted by R. K. Johnson, Sec'y.)

N. CALIFORNIA, September meeting. R. F. Bergstrom (Co-Author), Shell Oil Co., presented a paper entitled "'On the Spot' Lubricating Oil," by Bergstrom & T. S. Hodgson. (Submitted by G. H. Hommer, Sec'y.)

October. D. P. Thomas, Columbia-Geneva Steel Div. of U. S. Steel Corp., reviewed the Lubrication Engineers Manual compiled by C. A. Bailey of the Lubricants Testing Lab., National Tube Div. of U. S. Steel. (The manual contains clever illustrations and diagrams which are helpful in visualizing the methods by which the more important qualities of oils and greases are evaluated in the laboratory.)

November. "Mechanism of Rust Prevention," by D. W. Criddle, California Research Corp.

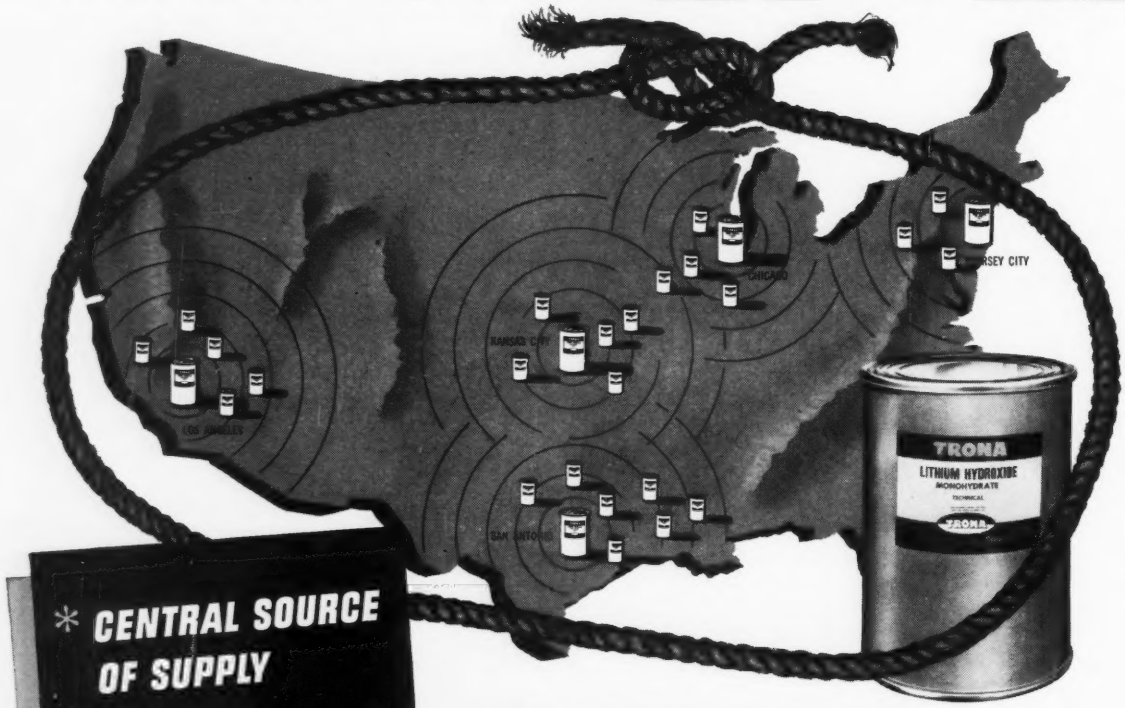
December. "Nature & Per-

(Continued on p. 421)

TRONA† LITHIUM HYDROXIDE

FOR MULTI-PURPOSE GREASES

...an essential product—tied in with service



* CENTRAL SOURCE OF SUPPLY

* STRATEGIC WAREHOUSING

* BETTER DELIVERIES

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†TRADEMARK AP&CC

GREASE MANUFACTURERS: There are three good reasons why Trona† should be your prime source of supply of lithium hydroxide monohydrate ($LiOH \cdot H_2O$), essential to the production of lithium base greases. (1) A **new and strategically located plant** at San Antonio, Texas (American Lithium Chemicals, Inc.). (2) **Convenient warehouse stocks** of lithium hydroxide, maintained in proximity to the major grease producing areas of the U. S. (see map). (3) **Better, faster deliveries,** because of advantageous rail and motor freight facilities. When planning your current, or future, requirements for LiOH we suggest you contact your American Potash & Chemical Corporation (Trona†) sales representative. His better service costs no more.

American Potash & Chemical Corporation

LOS ANGELES • NEW YORK • ATLANTA • SAN FRANCISCO • PORTLAND (ORE.)

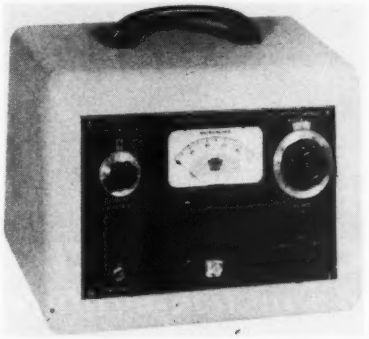
Producers of: BORAX • POTASH • SODA ASH • SALT CAKE • LITHIUM CHEMICALS • BROMINE CHEMICALS • CHLORATES • PERCHLORATES • MANGANESE DIOXIDE *and a diversified line of specialized agricultural and refrigerant chemicals.*

Plants: TRONA and LOS ANGELES, CALIFORNIA
HENDERSON, NEVADA
SAN ANTONIO, TEXAS (American Lithium Chemicals, Inc.)
Export Div.: 99 PARK AVENUE, NEW YORK 16, NEW YORK

New Products

Filter Cartridge. A new filter cartridge (pictured above) made of Hilite — a processed, high-grade fullers earth that is water-resistant — has been announced that is designed for filtering straight-run mineral oils for removal of all solid matter and reduction of acidity. The Hilite-fullers earth is machine-packed into a container including a metal center tube properly covered to prevent possibility of migration; because of the ability of the Hilite to absorb moisture, oils are kept dry. (The Hilliard Corp., Purifier Div., 98 W. 4th St., Elmira, N. Y.)

Lubrication Cycle Counter. A new lubrication cycle counter has been developed that provides (1) visual proof as a guard against bearing failure due to faulty lubrication, and (2) an automatic and permanent record of bearing lubrication. The new Alemite Accumatic lubrication-recording cycle counter (used with Type II Accumatic Centralized systems of lubrication) registers the exact number of times that the lubricant valve is discharged, revealing at a glance that the lubrication system is functioning at precisely the predetermined intervals selected to meet specific requirements. The unit, furnished as a kit, can be installed without removing the Accumatic valves from the Centralized system. It provides a permanent operational record of each Type II valve, greatly simplifying maintenance record keeping. The compact unit merely screws into the valve and extends but 1⅝" above it when in operation. The counter face swivels to any position for easy reading, and the totally-enclosed unit operates dependably over a wide range of temperatures. The piston action of the valve actuates the counter mechanism at every lubrication cycle; the unit automatically resets to zero when the counter reaches 99. (Alemite Div., Stewart-Warner Corp., 1826 Diversey Pkwy., Chicago 14, Ill.)



Corrosion Tester. The Labline-Pure Corrosion Tester (pictured above) is a new instrument to rapidly measure the rate of corrosion in all types of metals subjected to the corrosive effects of various liquids or gases. In the short space of a few hours, users of the tester can predict the amount of corrosion that may take place in five or ten years of field use. Probes have one protected corrosion strip and one exposed corrosion strip; automatic temperature compensation is obtained from the protected strip. The corrosion on the exposed strip causes the meter to indicate directly in micro inches of corrosion. Available in all types for long or short test periods, the probes are designed for high or low temperature testing, either in the lab or field. Standard models are wired for 115 volts, 60 cycles, A. C., but may also be obtained with D.C. converter for field work. Unit weighs only 12 pounds. Some of the potential applications are: (1) determining the corrosion rate of materials to be used in chemical reactors, mixers, processing lines of various types; (2) determining the corrosion inhibiting characteristics of gasoline additives, oil additives, and rust inhibitors added to auto radiators and various other processes, such as boilers; (3) determining the effectiveness of cathodic protection devices. (Labline, Inc., 3070-82 W. Grand Ave., Chicago 22, Ill.)

Vegetable Fatty Acid Lubricant. A new, hydrogenated fatty acid of vegetable origin has been developed for lubricating greases. Identified as "Swift's Hydrogenated Fatty Acid No. 62," the new product has a high melting point and high stearic acid content. Specifications on the product may be obtained from the manufacturer. (Swift & Co., Industrial Oil Dept., 1800 - 165th St., Hammond, Ind.)

Solvent Vapor Degreaser. A new, safety-engineered solvent vapor degreaser, designated "Model 22" (pictured above), is now available that can be operated with either vythene, tri-

(Continued on p. 416)

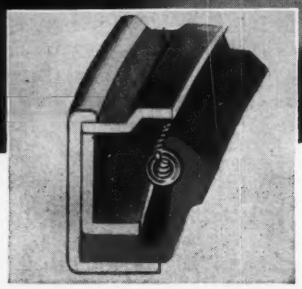
MORE OF THE GARLOCK 2,000

Will not **CRACK** *or* **HARDEN**
at high and low temperatures.

Garlock Silicone Rubber KLOZURE* *Oil Seals*

retain their original properties even after long exposure to temperature extremes that would quickly ruin organic rubber.

They are flexible and serviceable at temperatures as low as —90° F, and as high as 500° F . . . ideal for seals on automotive and aircraft products.



***Klozure Oil Seal with Silicone Sealing Element** for high speed, high temperature applications such as transmission cases, diesel engine crankshafts, and aircraft accessory gear cases. (Model 65 illustrated.)*

Extrusions and molded parts of Silicone Rubber are only part of "The Garlock 2,000"... two thousand different styles of packings, gaskets, and seals to meet all your needs.

It's the *only* complete line . . . that's why you get unbiased recommendations from your Garlock representative. Call him today or write for Oil Seal Catalog No. 10.

THE GARLOCK PACKING COMPANY, Palmyra, New York

For Prompt Service, *contact one of our 30 sales offices and warehouses throughout the U.S. and Canada.*

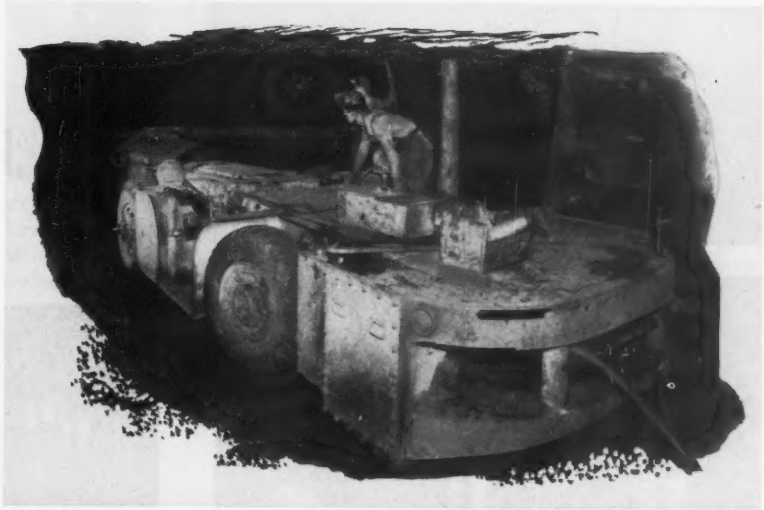
GARLOCK

Packings, Gaskets, Oil Seals, Mechanical Seals, Rubber Expansion Joints

**Registered Trademark*

Users save time and money with entirely new-type grease, resistant to

- **water washout**
- **temperature extremes**
- **rigorous mechanical working**



MANY USERS of heavy-duty equipment, such as this coal-mining machine, report that they have increased equipment life and lowered grease consumption and maintenance costs through the use of estersil-based greases.

Greases made with the revolutionary new grease thickener—Du Pont Estersil GT—give you all these properties.

Proved in service

Already, millions of pounds of grease made with Du Pont Estersil GT have been used in a wide variety of industrial applications. And the success attained has been as remarkable as the qualities of this unique product.

A coal mining company, for example, reports that one unit of its equipment formerly required from two to three *gallons* of regular lubricant per shift. But when an estersil semi-fluid grease was used, average consumption dropped 75%, to two to three *quarts* per shift.

Longer gear life

When rebuilding its machines, this company had always replaced the gears, as a matter of routine. But since switching to estersil grease, gears can be used over and over again without significant wear. This is because the estersil grease effectively seals out dirt, coal dust and other foreign matter.

Maintenance costs down 50%

Another industrial grease user reports that an estersil-based grease has caused his maintenance costs on one group of machines to drop from .185 cents to less than .09 cents per ton of product handled.

What it is

Du Pont Estersil GT is an entirely *new type* of grease thickener, a completely synthetic form of finely divided amorphous silica.

One of its unique features is that each minute particle is encased in a chemical "raincoat." This gives estersil-based greases positive, built-in water resistance . . . eliminates the danger of washout.

Non-melting estersil greases show little change in consistency when subjected to extremes of temperature. And under prolonged high-shear, high-temperature operating conditions, estersil greases show outstanding resistance to mechanical breakdown.

Du Pont Estersil GT is now available to grease compounders in commercial quantities. Check with your supplier or write us for more detailed information and samples of grease made with estersil.

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Better Things for Better Living . . . through Chemistry

Petroleum Chemicals

USE THIS COUPON

E. I. DU PONT DE NEMOURS & CO. (INC.)
Petroleum Chemicals Division • Wilmington 98, Delaware

☐ Please send literature on Du Pont Estersil GT. ☐ Please send samples of grease made with estersil. ☐ My lubrication problem is discussed on attached sheet.

Name.....

Company.....

Address.....

City.....State.....

Joint Conference Committee members A. C. West and H. A. Hartung flank the registration table to assist some of the 396 registrants that attended this year's conference.

Joint Lubrication

Officiating at the first day's session were: E. R. Booser, President of ASLE; E. E. Bisson, Organizing Chairman; D. F. Wilcock, Chairman, ASME Lubrication Activities Division; S. Abramovitz, Chairman, 1956 Joint Lubrication Conference Planning Committee; and John Boyd, Session Chairman.

Members of the 1956 Joint Lubrication Conference Planning Committee included: R. B. Purdy, A. E. Cichelli, E. E. Bisson, E. Rabinowicz, and in the back row, F. W. Ocvirk, S. Abramovitz, A. C. West, and H. A. Hartung.

Final program plans for the 1957 Annual Meeting to be held April 15-17 at the Sheraton-Cadillac Hotel in Detroit, were made during the conference by D. M. Cleaveland; E. G. Jackson; D. W. Sawyer; A. A. Raimondi; J. H. Gustafson; S. B. Twiss; L. B. Sargent, Jr.; C. R. Lewis, Chairman; R. H. Hendrick; and H. W. McCulloch, Jr. A tentative program will be published in the January issue of *Lubrication Engineering.*

Registrants await pocket badges and folder containing preprints of the papers presented at the conference. *Copies of all ASLE-sponsored papers are available through the National Office — see instructions for ordering and list of available papers in special program section of the July-August issue of* Lubrication Engineering.

Shown at the October Board of Directors meeting in Atlantic City are: (clockwise) C. T. Lewis, D. W. Sawyer, J. L. Finkleman, E. R. Booser, W. P. Youngclaus, Jr., J. O. McLean, and D. M. Cleaveland.

Another view of the conference meeting of the ASLE board of directors shows (clockwise from far left) D. M. Cleaveland, J. H. Fuller, and C. R. Schmitt, directors; R. F. McKibben, Central Vice-President; A. C. West, representing the Western Regional Vice-President; R. K. Gould, Chairman, Editorial Committee; M. E. Dougherty, Eastern Regional Vice-President; A. B. Wilder (with glasses), Midwestern Regional Vice-President; J. D. Lykins, A. E. Cichelli, C. T. Lewis, and D. W. Sawyer, Directors.

Conference Highlights

by R. B. Purdy

Socony Mobil Oil Co.

The 1956 Joint Lubrication Conference of ASLE & ASME proved highly successful as 396 completed registration during the three-day meeting at Atlantic City.

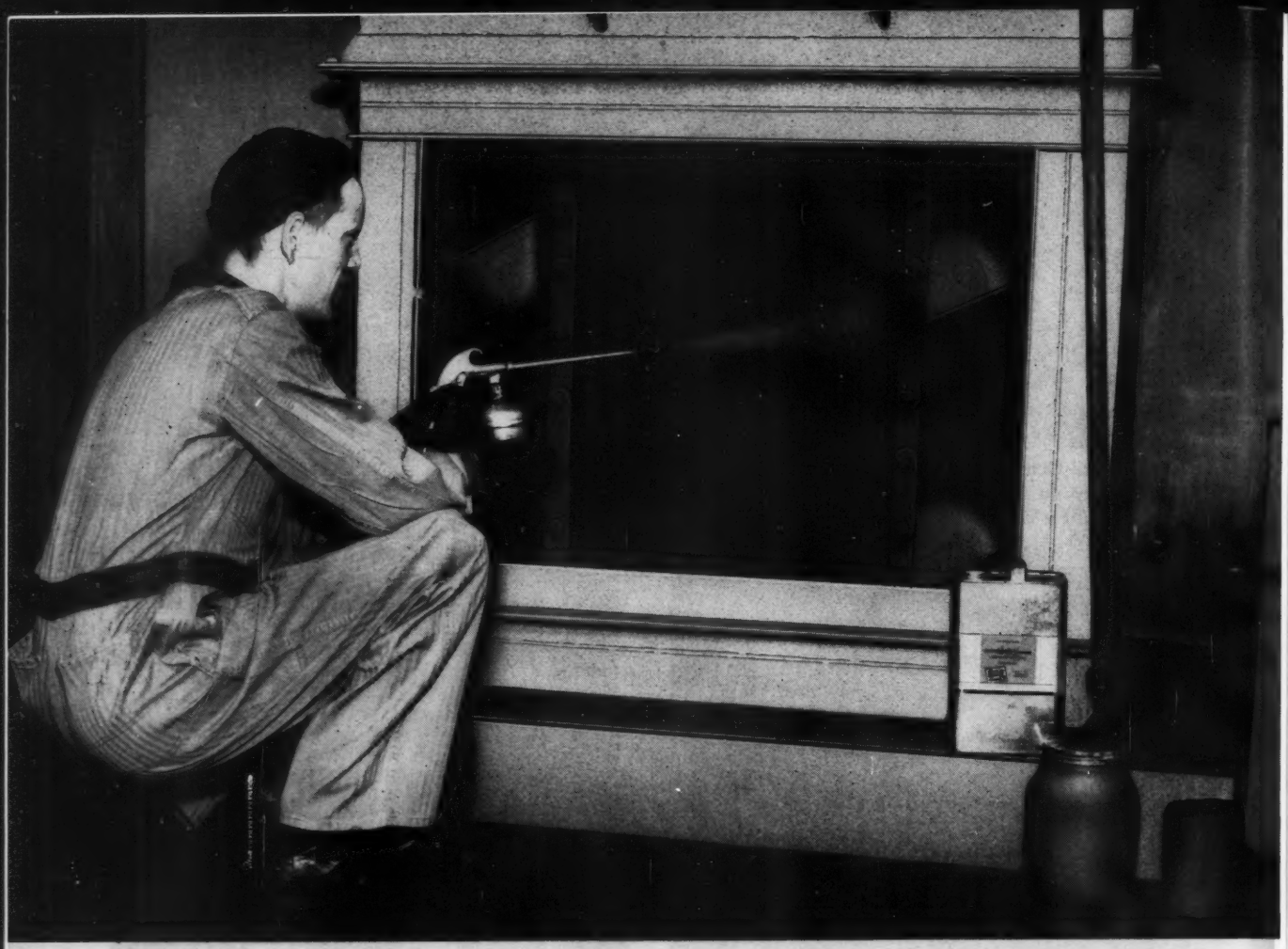
Highlighted were sessions on Bearing and Lubricant Problems in Nuclear Power Plants during the first day, and a reporter session on Hydrodynamic Lubrication held in the morning of the final day. Each registrant was provided a folder containing preprints of all papers available as a part of their registration fee.

During the Lubrication Conference Committee meeting held on October 9, Mr. E. E. Bisson was appointed Committee Chairman of the 1956-57 Conference and Mr. H. A. Hartung papers co-ordinator. Committee members for 1956-57 include: E. Rabinowicz, E. G. Jackson, Al Hundere, A. C. West, F. R. Archibald, and R. B. Purdy. A total of 22 papers will be required for the 1957 Conference. Suggested subjects include: Lubrication in Liquid Metals, Gas Lubricated Bearings, High-Temperature Lubricants and Lubrication, Low-Temperature Lubrication, Hydrodynamic Instability, Physical Properties of Lubricants, Wear, Non-metallic Bearings, Cutting Fluids and Drawing Compounds, Fatigue in Rolling Contacts, and Boundary Lubrication. Authors desiring to prepare papers in these areas are urged to contact either of the sponsoring Societies for further information.

Plans for the activities of the Technical Advisory Board of ASLE during the forthcoming year were discussed at a meeting attended by T. A. Marshall; A. A. Raimondi, Vice-Chairman; H. M. Trowbridge, T. W. Havely; R. W. Blair; S. R. Calish, Jr., Chairman; M. B. Peterson; J. O. McLean, ASLE Vice President-at-Large; C. W. Nichols, Jr.; C. L. Miller; and W. D. Whalen.

Plan to Attend:

1957 Joint Lubrication Conference
October 7, 8, and 9
Royal York Hotel
Toronto, Ontario, Canada



'dag' dispersions . . . *a touch does so much!*

"Sticky" conveyor problem solved by colloidal graphite lubrication

For a number of years, Whitehall Pharmacal Company, nationally known pharmaceutical manufacturer in Elkhart, Indiana, had lubrication problems with the bucket conveyor to its coal-storage elevator. Pin wear was excessive, due to abrasive coal dust and the corrosive effects of moisture . . . until they tried lubrication with a **'dag'** dispersion of colloidal graphite in mineral spirits.

Diluted 1:7 with mineral spirits, **'dag'** dispersion No. 2404 is now sprayed on the conveyor links, as shown in the photograph, at two-week intervals. The compressed-air jet carrying the dispersion blows away accumulated dirt . . . lets the volatile carrier deposit a microscopic film of graphite around the pin and link. The resulting *dry lubricating film* is exceptionally durable, provides effective lubricating action, and inhibits corrosion. Whitehall reports that maintenance expense for the conveyor has been drastically cut and down-time all but eliminated.

'dag' dispersions are ideal for conveyor lubrication since they resist abrasion, provide lubrication under extreme pressures, and are not affected by high temperatures. They are suitable for application by automatic oilers and mist lubricators.

Write for more information, contained in Acheson Bulletin 423.

100th Anniversary

1891—SILICON CARBIDE
1895—SYNTHETIC GRAPHITE
1906—COLLOIDAL GRAPHITE

ACHESON COLLOIDS COMPANY
PORT HURON, MICHIGAN
. . . also Acheson Colloids Ltd., London, England

ACHESON COLLOIDAL DISPERSIONS:
Graphite • Molybdenum Disulfide • Zinc Oxide • Mica and other solids

'dag' is a registered trademark of Acheson Industries, Inc.

ACHESON COLLOIDS COMPANY
Port Huron, Michigan, Dept G-11

Yes, I want to get your free bulletin describing **'dag'** Dispersions for High Temperature Lubrication.

Name_____

Title_____

Company_____

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City_____ Zone____ State_____

Lube Lines

by A. F. Brewer*

RELATION OF OPERATING CONDITIONS

Machinery can function most effectually when the lubricants used are capable of performing dependably under whatever extremes of operating conditions may prevail. Consequently, it is most important to be fully conversant with these extremes as they relate to temperature, load, and speed, and the possibility of lubricant contamination from outside sources. Too often there is a tendency to blame the lubricant for some failure when, in reality, the cause goes back further — to lack of realization of the operating conditions and the selection of a lubricant incapable of furnishing dependable lubrication under these conditions.

Evaluation of the relation of the operating conditions to the physical and chemical properties of lubricants, requires an item by item study of temperature, load, speed, and contamination. Rarely are all extreme one way or the other. Where very high temperatures may be developed at bearings or in gear cases, surface speeds are not always very high. Loads, however, may be. In fact, load and temperature very often work together. Overload causes an increase in temperature, especially if there is an approach to boundary lubrication. Extreme-pressure lubricants obviate this possibility if the EP characteristics of the oil or grease are adequate. In other words, here is a condition where management should insist that EP properties be a major consideration regardless of reasonable price.

Fortunately, it is possible to provide means for temperature control by water, oil, or air cooling. This should be adequate whatever the cooling medium, because it must be realized that increase of temperature will cause increased fluidity of lubricants, even to causing greases of otherwise suitable consistency to become so reduced as to result in leakage.

It is equally fortunate that the science of petroleum refining and compounding has perfected methods of segregating suitable lubricating stocks which become the basis for compounding high-temperature oils and greases capable of functioning within the acceptable hardness ranges of modern steel alloys. When even higher operating temperatures must be involved and special machine parts lubricated, there are certain solid and synthetic lubricants available. Graphite, for example, has a maximum usable temperature of around 1500°F.

Load on bearings or gear teeth, however, cannot be as readily controlled as temperature. Normally, load is an inherent function of the machine whose factor of safety provides for a certain amount of overload and, probably, increase in speed. Management meets this contingency by thoroughly investigating the load-carrying ability of prospective lubricants. Systems of automatic lubrication are an aid to satisfactory performance inasmuch as means are provided for circulation or continual renewal of the lubricating film. This obviates the possibility of hot spots developing.

The actual pressure which may be developed within the high-pressure area of a plain bearing, or along the line of contact between gear teeth, is dependent upon the load. Pressure must be regarded as static and operating. The former is due to dead weight of machine parts when idle, especially on bearings. Normally, the static pressure is less than the operating pressure which will vary widely according to the function of the machine. On a metal press or steel rolling mill the impact pressure which is developed upon gears and bearings is very severe. Where there is continuous motion, the operating pressure normally levels off.

The machine designer plans for a certain speed range; although in full realization that some types of units can be run faster, he includes a certain factor of speed safety beyond the normal range. The extent to which any machine may be run at overspeed depends upon the product and the ability of the process to adapt itself to higher run-off speed.

Speed must be considered in connection with lubrication due to the relation to viscosity or consistency. The normal premise is that the viscosity or consistency of a lubricant can be reduced as higher speeds are involved; this, by reason of the fact that lubricants of greater fluidity will show less tendency to develop internal or molecular friction when subjected to high-speed agitation or film formation.

It is obvious that a contaminated lubricant is not an effective lubricant. Usually this is because the contaminants, either solid or fluid, definitely have no lubricating value. Solid foreign matter such as dirt, dust, or metallic particles are abrasive and can exert a serious wear effect upon relatively soft bearing metals, ball or roller bearing parts, or gear teeth. The more precisely the parts have been finished and assembled, the more costly they would be to replace — and the more easily (usually) are they damaged by abrasive non-lubricating materials.

Water is naturally not an abrasive, but its deleterious effect is just as serious because it promotes rusting of steel parts, corrosion of non-ferrous parts, and the formation of acidic sludges.

The prevention of lubricant contamination is a housekeeping problem, provided the machinery is properly designed and assembled. It is a management problem because contamination too often is a sin of commission on the part of plant personnel. Lubricants of the most ideal characteristics as to stability and effectual additives become undependable when their lubricating ability is thrown off balance by contaminants.

*Consultant, and Author of "Basic Lubrication Practice."

SIR HENRY BESSEMER *concentrated on steel metallurgy when England needed cannons for the Crimean War. Steel was then being made from wrought iron by the slow, costly crucible method. He sought to produce it faster by blowing air through molten pig iron. His first attempt, in 1854, succeeded.*

But Bessemer's process required Swedish iron and could produce only high carbon steel. With English irons, it failed completely. For years, Bessemer tried to produce mild steel. The final solution came when manganese was added in the form of spiegeleisen, opening the door to the modern age of steel.

Great Names in Steel Making #III

When you look at Henry Bessemer's great achievement, two things stand out. First, his research was prompted by a critical war-time need. Second, his process was not perfected until freed from its dependence on imported iron.

Men familiar with modern rolling mill practice will note interesting points of similarity in the development of an all-American lubricant replacing palm oil.

The search for such a lubricant began during World War II, when the palm oil then indispensable for cold rolling had to be imported across submarine-infested oceans. Success came midway in the Korean War, when Ironsides engineers announced the perfecting of Palmoshield, "the palm tree that grows in Ohio."

Palmoshield ended, forever, our country's dangerous dependence on imported palm oil. Within six months of its appearance, two-thirds of our major tin plate mills were using or testing Palmoshield. In the four years since, its application has steadily broadened to the rolling of sheet, long terne and coating lines as well.

Palmoshield has every desirable characteristic of palm oil, but is compounded entirely of domestic materials. It need not be stockpiled. Fatty acid content can be controlled within ½%. Most gratifying of all, in mill after mill its use has resulted in increased production.

With few exceptions, major rolling mills today are either using Palmoshield, or have fully tested it in their production so as to be prepared to adopt it without changing their mill operation at any future time.

In the past four years, Ironsides engineers have successfully compounded Palmoshield for all different methods of application. They know how and stand ready to "custom tailor" Palmoshield for the particular method you employ. Their experience, and the advantages of an unfailing domestic source of supply, can both be yours through a letter or phone call addressed to The Ironsides Company, Columbus 16, Ohio.

By the makers of Palmoshield
"the palm tree that grows in Ohio"

JOSEPH MARGULIES.

ASLE News Notebook

Compiled by
R. D. McCormick

Executive Reports

To maintain past efficiency and to relieve the increased work loads on the National staff brought about by increased services to the membership, the addition of an office employee was recommended. Membership billing will be started at the beginning of December this year to further relieve the increased workload during the first part of the year.

Creation of a special committee on advertising for the journal was recommended. The committee would recommend ways to improve the volume of advertising to expand the editorial content of Lubrication Engineering in keeping with the needs of its readers and develop methods of improving the service function provided to the advertiser. Committee members appointed included: J. L. Finkelmann, Chairman; J. Boyd; W. H. Fowler, Jr.; J. J. O'Connor; D. W. Sawyer; and R. D. McCormick.

Complete revision of the By-Laws was deemed necessary including clarification of the membership grades *Fellow*, *Associate*, and *Retired*. Action was taken to insure that the By-Laws Committee would increase their efforts to complete this work.

All Section Treasurer's Reports were approved.

Shown at the October Board of Directors meeting were J. W. Peterson, S. R. Calish, Jr., A. B. Wilder, J. D. Lykins, A. E. Cichelli, D. W. Sawyer and J. L. Finkelmann.

Report of the Vice President-at-Large

J. O. McLean reported that procedures have been established for inaugerating research projects and that each technical committee is now searching for projects which the Society can sponsor. No projects are ready for presentation at this time.

Administrative Secretary's Report

With the growth of ASLE activities and the subsequent recognition by professional and lay groups throughout the world, W. P. Youngclaus, Jr., predicted an increase in membership to 10,000 members within the next few years. Potential membership for the Society appears to be about 35,000 members.

National Staff procedures have been re-organized to provide additional services to the various committees of the Society and to speed up operational details in accord with the recommendations of the Organization and Operations Committee.

Eastern Region

Four Area Representatives have been appointed for the Eastern Region. The Baltimore Section is organizing a Lubrication Engineering Course. Further details will be provided as they become available.

Central Region

Three Area Representatives have been appointed. The initial meeting of the Columbus Section was attended by 42. An offer was made by the Dayton Section to turn over the jurisdiction of three Ohio counties to the new Columbus Section to provide better area distribution. Action on this was referred to the Board.

Canadian

No report.

Mid-Western Region

Approval of the new Duluth-Iron Range Section has been obtained and the first two meetings of the Section have been well attended. The educational course sponsored by the Chicago Section registered approximately 110 students of which 80% are not members of ASLE. With the last session to be held on November 19, 30 new members have already applied for membership from this course.

Western Region

Complete programs for the year have been planned by both Sections in the Western Region. A Section Officer's Planning Conference has been scheduled for November by the acting regional Vice-President with the cooperation of the Section Chairman from the Los Angeles and Northern California Sections to cover the following topics: *Why ASLE?, Successful Section Meetings, Building Membership, Section Finances, and ASLE In Action.* (Further details will be reported on this conference in a future issue of Lubrication Engineering.)

Technical Advisory Board

Industry committees are being formed for the Machine Tool Industry and for Non-Ferrous Metals. A subcommittee on viscosity classification of industrial lubricants has been formed to study various proposed systems.

Symposia for the individual technical committees are recommended by the TAB to cover specific subjects of interest to the committees. The technical committee on gears is interested in such a symposia and is making plans for a future program.

Committee Reports

Lubrication Conference

Attendance at this year's conference was 396, compared with 287 in 1954 and 267 in 1955. More than 250 registered for the first day's sessions. Approximately two-thirds of the papers were contributed by ASLE authors. E. E. Bisson has been appointed Chairman of the 1957 Conference Planning Committee which will be held in Toronto, Ontario, Canada on October 7-9 at the Royal York Hotel.

Nominations

At a meeting of the Nominations Committee on October 9 a tentative slate of candidates for 1957 was selected. Clearance is now being obtained so that a final report can be submitted at the January meeting of the Board of Directors.

Education

The education course covering Lubrication Engineering is being rearranged for 1957. New Chairmen will be selected. This committee is also working on a revised manual for Section level educational courses.

Awards

All Officers, Directors, and Section Chairmen of ASLE have been solicited for nominations for the 1957 awards. Nominations are expected to be made at the January meeting of the Board of Directors. Nominees for the awards must meet the following award requirements:

Walter D. Hodson Award

An award of twenty-five dollars and an appropriate certificate is made to an ASLE member 30 years of age or less for the best paper presented at any Section or National meeting of ASLE, or published in the Society's official journal during the period September 1 through August 31 of the year preceding an annual meeting of the Society. The paper shall be limited to 5000 words and shall deal with the field of lubrication or an allied subject, and shall not have been published previously. The recipient shall be the sole author of the paper. It is not necessary that the award be made annually should there be no qualified recipient. The award is made to stimulate the interest of young engineers in the science of lubrication and the activities of ASLE.

ASLE National Award

This award is made in recognition of an outstanding contribution to the field of lubrication engineering or allied fields. It is not necessary that the recipient be a member of ASLE. The award consists of a certificate symbolizing honorary membership in the Society. Two awards will be the maximum awarded in a year's period. Presentation will be made at the annual meeting. Should there be no qualified recipient the award need not be presented annually.

Captain Alfred E. Hunt Memorial Award

Presented to an ASLE member for the best paper presented at any Section or National meeting of ASLE or published in the journal of the Society during the period September 1 through August 31 of the year preceding the annual meeting of the Society. The paper should be limited to 5000 words and shall deal with the field of lubrication or an allied subject, and shall not have been published previously. The recipient must be the sole author of the paper. The award need not be presented annually should there be no qualified recipient. With this award the Society seeks to acknowledge outstanding papers presented by members of the Society. The award shall be a suitable medal or certificate.

Wilbur Deutsch Memorial Award

This award is made to an ASLE member for the best paper on the practical aspects of lubrication and presented before any Sectional or National meeting of ASLE or published in the Society's journal during the period September 1 through August 31 of the year prior to the annual meeting of ASLE. The paper shall be limited to 5000 words and shall deal with those phases of lubrication engineering of interest to plant personnel responsible for lubrication of industrial equipment, and shall not have been published previously. The recipient shall be the sole author of the paper. It is not necessary that the award be made annually should there be no qualified recipient. The award is made to acknowledge outstanding papers of a practical nature presented by ASLE members and consists of a suitable medal or certificate.

Projects Committee

Mr. R. Kraus has been appointed chairman of the committee. Work has been started on a comprehensive list of trade names within the field of lubrication and its allied subjects as suggested at the June meeting of the Board of Directors.

Journal Bearing Research

Abstract revisions have been completed and modifications are in process prior to publication processing. The work is expected to be completed within two months.

Annual Meeting

Preparations for the 1957 annual meeting, to be held April 15-17 in Detroit at the Sheraton-Cadillac Hotel, are progressing according to schedule.

Exhibits Arrangements

Literature for exhibit space for the 1957 annual meeting has been sent to all prospective exhibitors. Contracts for 25 booths have been received by the National office.

Abstracts

Preparation of rules related to abstracts to be published in *Lubrication Engineering* are in preparation and the first group of abstracts have been forwarded to the technical committees for processing to be incorporated into the January issue of the journal.

Editorial

Additional equipment necessary for the preparation of preprints of papers presented at National meetings of ASLE has been approved by the O & O Committee and purchased. A survey of readership of the journal by an independent firm was presented to the Board of Directors. R. K. Gould, editor of *Lubrication Engineering*, stated that steps have been taken to acquire more papers dealing with the practical scope of lubrication to improve the journal. Local Sections provide a source of such papers although these may not be in a readily publishable form. Given proper editorial assistance more papers presented before the local Sections could be published for the ultimate benefit of the members and subscribers. (Prospective authors requiring assistance with practical papers should write the National office.)

Program

Papers for the 1957 annual meeting have been received and the tentative program is complete. Authors have followed the deadline requirements much better than in previous

years. (A complete list of the papers tentatively scheduled will appear in the January issue.)

HANDBOOK

Final revision of the outline for the Lubrication Engineer's handbook has been completed and material for the various sections of the book is beginning.

INDUSTRIAL RELATIONS

A Chairman for this committee is currently being sought.

INDUSTRIAL REPRESENTATIVE

The possibility of combining this committee with the Industry Relations committee is being considered.

ORGANIZATION & OPERATIONS

First drafts of the operations manual are expected to be completed before the end of 1956. Analysis of the operations of the National office by W. H. Fowler, Jr., has been completed and approval of his suggestions are recommended.

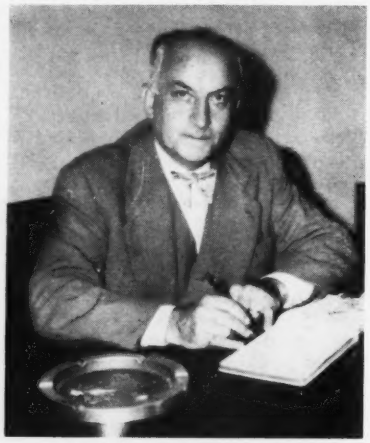
Board Actions

Madison, Fayette, and Union counties of the state of Ohio were withdrawn from the jurisdiction of the Dayton Section and incorporated into that of the Columbus Section. Rules for the Lubrication Conference, jointly sponsored by the ASLE and the ASME, were approved subject to yearly review. The board moved to hold the 1960 Annual Meeting & Exhibit in Cincinnati, Ohio. Motion passed. A portion of the total dues collected from Industrial members of the Society not to exceed 50% of the total was to be set aside for additional editorial help in rewriting practical papers for publication in the journal by board action.

Next meeting of the Board of Directors was scheduled for 9:00 A.M., Wednesday, January 16, 1957 at the Sheraton-Cadillac Hotel in Detroit, Michigan.

ASLE Personalities

On October 22, 1956 the National Office was honored by a visit from M. Albert J. Trompier, Chief Engineer, Lubricants Service, of the Compagnie Générale du Duralumin et du Cuivre, Paris, France. M. Trompier was visiting the United States to consult various filter manufacturers in an attempt to solve reclamation problems in the continuous filtration of rolling oils and cutting fluids used during the manufacturing operations of Cégédua. He described some of the problems encountered in the plants throughout France, including corrosion of conveyor systems and disposal of industrial wastes.



Albert J. Trompier

Compagnie Générale du Duralumin et du Cuivre has an interesting hot rolling process involving the intermolecular bonding of aluminum for radiators and heat exchangers. Aluminum sheets approximately 3 mm thick are surface treated by scrubbing and hot air drying. Graphite, as an antiseizing agent, is applied by a silk screen printing process to one of the surfaces. By hot rolling the two sandwiched sheets, after the second surface treated sheet has been placed over the graphite treated surface, the final length is attained and intermolecular welding occurs. Shearing at a diagonal one edge of the material permits the graphite treated areas to be pried apart so that by introducing hydraulic pressure the graphite is flushed from the sandwich and the nonbonded wall area is formed into tubing. Tube diameter is controlled by a second rolling operation. (Note that graphite serves as a lubricant between the two surfaces during rolling as well as a contaminant to prevent welding occurring in the tubing walls.)

Preventing the formation of oxide coatings on the aluminum sheeting prior to the bonding process is critical. M. Trompier stated that oxygen action in the formation of these oxides need not be controlled up to temperatures of 250°C providing water is absent. When both water and oxygen are present, however, the formation of the oxide coating is very rapid.

Reflecting on the growth of the science of lubrication and the need for trained personnel M. Trompier stated, "The young engineer or chemist cannot be a good lubrication engineer until he has obtained considerable experience, because each lubrication problem is so specialized." "The chemist is often concerned more with boundary lubrication rather than the other forms approached by the mechanical engineer working in the [field of] lubrication."

M. Trompier has been a member of ASLE since 1950. Prior to his visit the St. Louis Section presented him with a new ALSE lapel pin as a memento of his visit.

Guests and officers present at the October meeting of the Chicago Section included S. D. Craine, who spoke on "Gear Lubrication"; A. B. Wilder, Midwestern Regional Vice-President; J. N. Waddell, Section Vice Chairman; R. K. Gould, Editor, Lubrication Engineering; R. G. Grothus, Section Chairman, and Mr. K. Sitharama Rao of the Standard-Vacuum Oil Co., Madras, India.

Detroit Next!
April 15, 16, 17, 1957
Sheraton-Cadillac Hotel
1957 Annual Meeting

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MOLYKOTE is manufactured from the purest molybdenum disulfide powder available to industry today. It is compounded under laboratory supervision to retain this purity in the manufacturing process and has achieved an enviable reputation for overcoming the toughest lubrication problems in industry.

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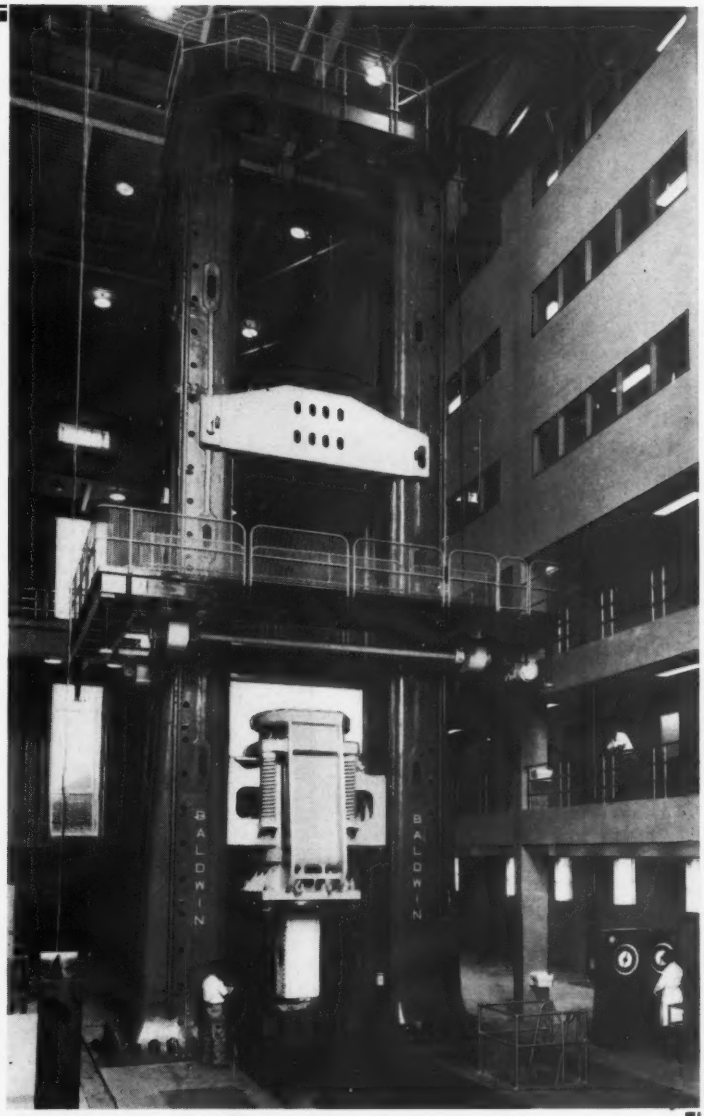

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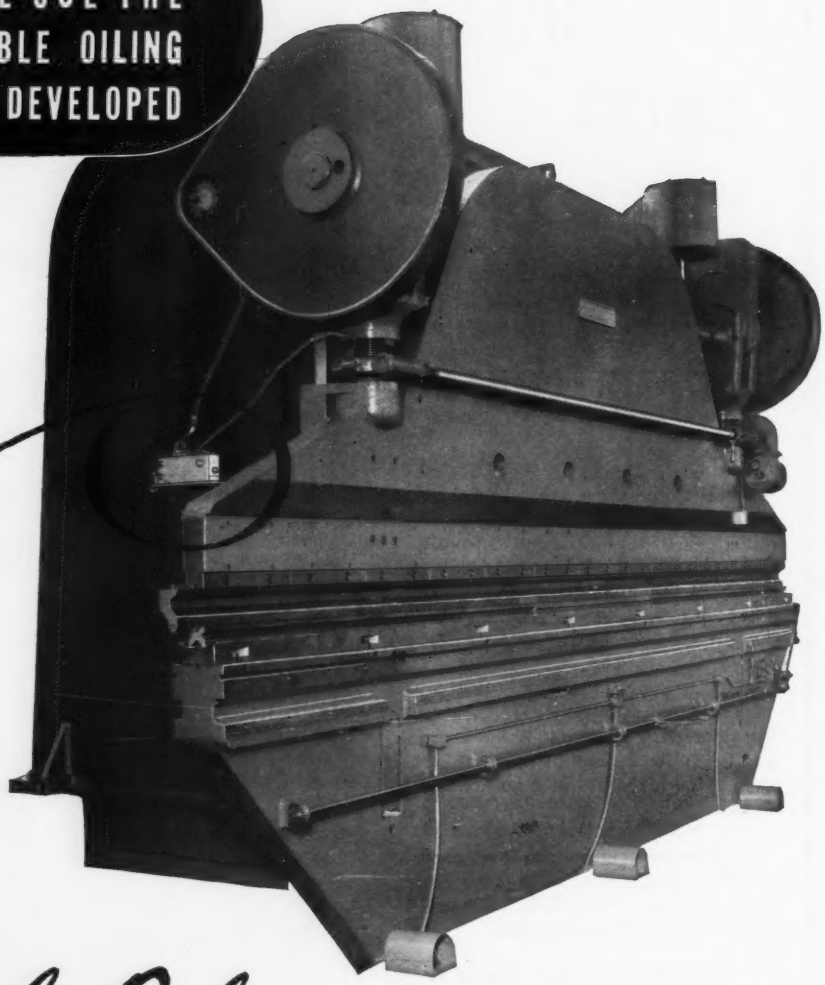

Illustrated is Madison-Kipp Lubricator Model FD installed as original equipment on a ⅜" by 20' Cincinnati Press Brake, manufactured by the Cincinnati Shaper Co., Cincinnati, Ohio.

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The Mechanism of "Free" Rolling Friction

D. Tabor*
Dept. of Physical Chemistry
University of Cambridge
Cambridge, England

When a hard steel sphere rolls over a flat metal surface at moderate loads, plastic grooving of the surface occurs and the resistance to rolling is primarily due to plastic displacement of the metal ahead of the sphere. With repeated traversals of the same track, there is a gradual growth in the width of the track and a decrease in the rolling resistance until an equilibrium state is reached. At this stage the deformations are elastic, and the friction and track-width remain more or less constant. This rolling friction is not reduced by the presence of boundary lubricants, just as in the plastic range. The major part of the paper deals with a study of the mechanism of rolling friction in the elastic range. It is shown that the rolling resistance cannot be due to interfacial slip of the types described by Reynolds and by Heathcote. The new point brought out is the suggestion that the major source of "free" rolling friction is elastic hysteresis losses in the solids themselves.

It has long been a matter of common experience that the work required to roll bodies over one another is generally much less than the work required to slide them. Although a large body of work has been described on the mechanism of sliding friction, relatively little work has been carried out on the basic mechanism of rolling friction. Before dealing with this subject, it is necessary to point out that there are two broad fields of rolling friction. In an automobile or railway locomotive, the driving wheels exert a considerable horizontal traction and the behavior is very much complicated by the marked slippage that may occur between the wheel and the road or rail, even when the horizontal traction is considerably less than the force necessary to overcome the ordinary sliding friction between them. This has been studied theoretically by Carter[1] in England, by Föppl[2] in Germany, and more recently by Poritsky;[3] and (in a somewhat different form) by Mindlin[4] and his school in America. The other type of rolling occurs when a sphere or cylinder rolls freely over a flat surface or between two parallel surfaces as in ball and roller bearings. Here the tangential tractions are trivial. Although the two types of rolling must merge into one another, the distinction is a useful one. This paper deals essentially with "free" rolling under conditions where the tangential traction is relatively small.

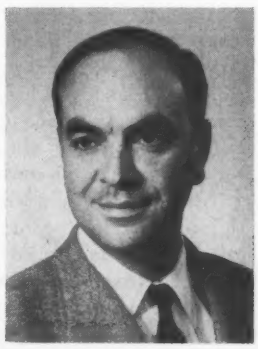
ROLLING IN THE PLASTIC RANGE

The first part of this work was carried out by Eldredge with a simple and extremely elegant piece of apparatus designed by him.[5] A hard steel ball is placed between two flat parallel blocks of a softer metal, and the force necessary to produce rolling is measured. The apparatus is shown schematically in Figure 1. The lower surface is attached rigidly to the base of the apparatus. The upper surface is mounted on a beam which can swing freely in the horizontal and vertical planes. The weight of the beam is supported by a counterbalance spring, whilst the load is applied as a dead weight. A micrometer screw drives the upper surface over the lower so that the interposed ball rolls smoothly between them. The upper surface is not attached directly to the rigid part of the beam but to a pair of connecting spring strips which are deflected in a horizontal plane by the rolling frictional force. A post is attached to the main body of the beam and another to the upper specimen holder. The small relative movement between these posts produced by the rolling resistance is magnified about twenty-fold by a fine V-shaped wire which carries a stylus at its apex. The stylus records the deflections on a sooted glass plate. These deflections are at right angles to the direction of movement of the beam (and the stylus) as a whole, so that a record is obtained on the sooted glass of the rolling resistance against the distance travelled by the upper surface. If the soot layer is wetted with a small quantity of a light mineral oil, it acquires a homogeneous texture and the resolution is extremely good.[6] By using spring strips of different stiffnesses, tangential forces ranging from 0.1 to 500 gm. can be measured. The vertical load can be varied from about 10 to 10,000 gm. The speed of rolling was low and, in general, did not exceed 1 cm./sec.

With this apparatus it is generally found that even for the smallest loads the first traversal produces plastic grooving of the metal surface, and the force to produce rolling is essentially the force required to displace the metal plastically from the path of the ball. If A is the cross sectional area of the groove produced, and p is the local yield pressure of the metal (comparable to the Brinell hardness), the rolling force F may be expressed to a good approximation by the relation

$$F = Ap$$

With repeated traversals of the same track, the track width increases and the rolling force for each traversal diminishes. This part of the process is one which is dominated by the plastic displace-



D. Tabor

This paper was presented at the ASLE 11th Annual Meeting, Pittsburgh, April 6, 1956.

*International Fellow (1955-56) Stanford Research Institute, Menlo Park, California.

ment of the metal, and it is, therefore, not surprising to find that the rolling friction is the same whether the surfaces are clean or are lubricated with a very effective boundary lubricant. The rolling behavior in this region has been described fully by Eldredge and Tabor[7] and will not be discussed further here.

After repeated traversals of the track, an equilibrium state is reached. This generally occurs after about one hundred traversals, and appears to be due to three main effects: the increased track width, the work hardening of the metal, and a slight change in the curvature of the track. As a result of these factors, the ball forms an ellipse of contact within the boundaries of the existing track. Under these conditions the deformations are essentially elastic, and there is little appreciable change in the rolling friction or track width with subsequent traversals. The rolling friction F is constant, is scarcely affected by the presence of lubricants, and varies with load W and ball diameter D according to an empirical law of the form

$$F = kW^n/D^m \qquad (1)$$

where $n = 1.7$ to 1.85, $m = 1.5$ to 1.7, and $k =$ constant for any one given metal. The rest of this paper deals specifically with this stage of the rolling process, and with the more general problem of rolling friction under conditions where the rolling process produces negligible permanent deformation of the surfaces.

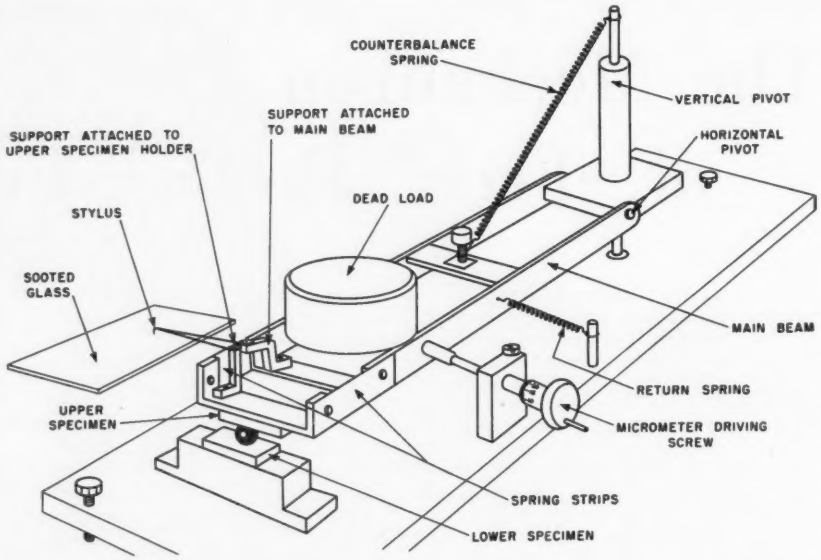


Figure 1. Eldredge apparatus for measuring rolling resistance when a hard sphere rolls between two parallel flat surfaces.

ROLLING OF CYLINDERS IN THE ELASTIC RANGE

Apart from some early observations by Leonardo da Vinci, the first serious study in this field was by Coulomb[8] who found that in the rolling of wooden cylinders, the rolling friction is roughly proportional to the load and inversely proportional to the diameter of the cylinder. Almost a hundred years later Osborne Reynolds[9] observed that when a hard metal cylinder rolls over a flat rubber surface, it moves forward, in each revolution, a distance less than the circumference of the cylinder. This is because the cylinder measures out its circumference on rubber which is stretched within the band of contact. From his earlier work on the slip of leather belts over cylindrical pulleys, Reynolds concluded that there was similar slipping between the roller and the rubber surface, different elements of the rubber being stretched by different amounts within the region of contact.

In order to study Reynolds' theory in greater detail, a ½" diameter steel cylinder was supported on two small ball bearings and rolled over a flat block of red bung rubber.[10] Under heavy loads it was found that in a single revolution the cylinder travelled forward a distance 10% less than its circumference. To see to what extent this involved interfacial slip, a small hole (XY, Figure 2a) was drilled diametrically through the roller and its edges painted with printer's ink. Under light static loading a clear circular imprint was formed (Figure 2b). During rolling,

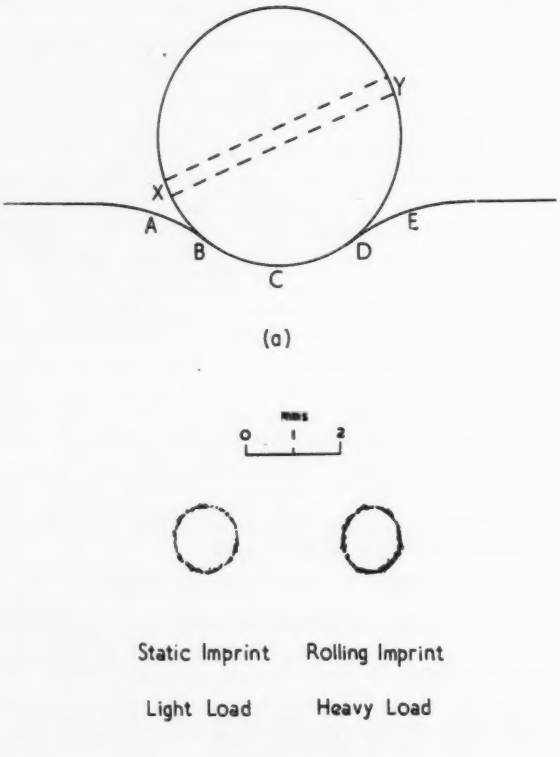


Figure 2a. Arrangement for examining rolling of a metal cylinder over a rubber surface.

Figure 2b. The imprint formed for light static loading is a sharply defined circle. For rolling under a heavy load, the imprint is a sharply defined ellipse.

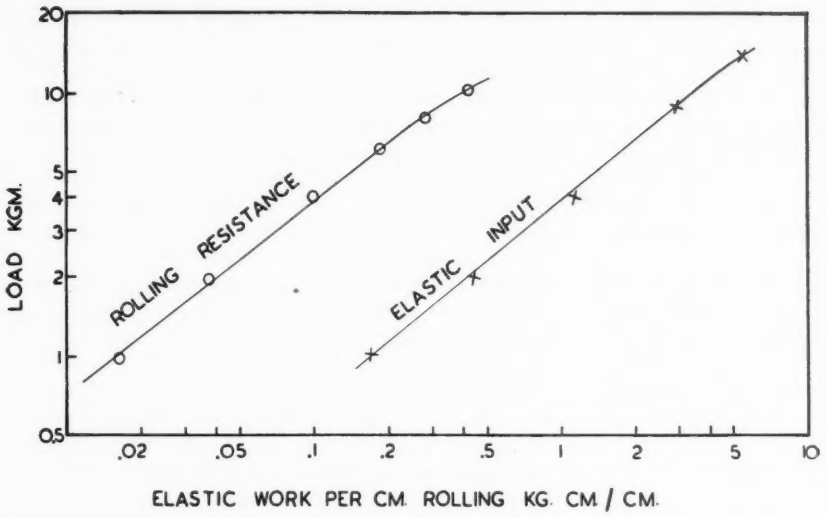


Figure 3. Quantitative results for rolling a metal cylinder over a surface of rubber known to possess a hysteresis loss factor of 9%. Curve on right, calculated elastic input-energy per centimeter of rolling.

an equally sharp imprint was formed, but now the imprint was elliptical with the minor axis 10% smaller than the major axis. This shows two things. First, the rubber is stretched before it enters and after it leaves the region of contact (regions AB, DE, Figure 2a), and the cylinder merely measures out its periphery on rubber that is stretched — more or less uniformly — by 10%. Secondly, Reynolds suggested that the stretching of an element of the rubber at B may be different from that at C so that there would be a second-order slip between B and C to accommodate the change in stretching. The sharpness of the elliptical imprint shows, however, that this slipping, if it does occur, is of negligible proportions and quite insufficient to account for the observed rolling friction. This is confirmed by the observation that when the surfaces are lubricated with glycerine the rolling friction is substantially unchanged.

The only source of energy loss is elastic hysteresis. Its magnitude was determined by cyclicly loading and unloading the ½" cylinder on the same rubber (loading direction normal to the rubber surface), the time of one complete cycle being approximately the same as the time taken, in the rolling experiment, for the cylinder to roll a distance equal to its arc of contact. The depth sunk in by the cylinder was measured by a dial gauge, and a force displacement curve was plotted. Typical hysteresis loops were obtained, and it was found that, if the time of a complete cycle was kept constant, the hysteresis loss factor* was almost independent of the strain. For the rubber used, the hysteresis loss amounted to 9% of the input elastic energy. The elastic input energy per centimeter of rolling could be calculated from the known depth sunk by the cylinder and from the length of the arc of contact. This quantity (in Kg.cm/cm which is equivalent to the unit of force in Kg.) is plotted for various loads in Figure 3. The observed rolling force is plotted on the same figure. The curves are parallel, the rolling friction values being almost exactly 9% of the input energy.

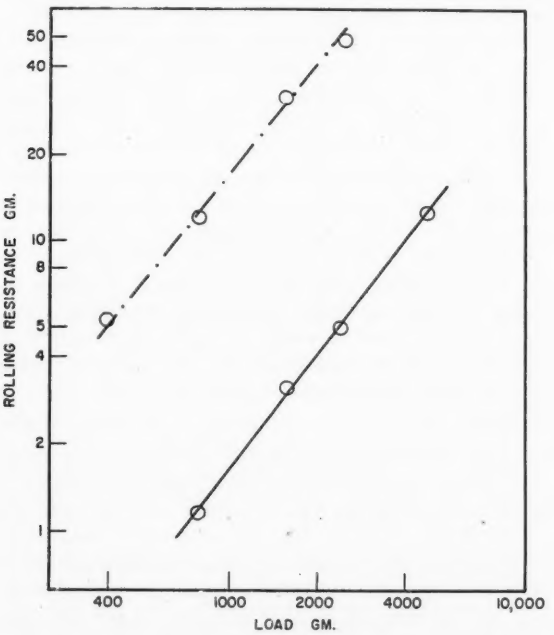


Figure 4. Rolling friction of a steel sphere on two sorts of rubber surfaces. The broken curve is for a rubber having a hysteresis loss factor eight times as great as for the other rubber.

ROLLING OF SPHERE ON FLAT RUBBER

Similar experiments were carried out for a steel sphere rolling on a flat block of rubber. Since the rolling friction is generally less than 1% of the normal load, the stresses during rolling may be assumed to be essentially the same as for static loading. Neglecting the deformation of the sphere and using Hertz's equation, it may then be shown[11] that the elastic work done per centimeter of rolling is

$$\phi = 0.54\ W^{4/3}\left[\frac{1-\sigma^2}{E}\cdot\frac{1}{D^2}\right]^{1/3} \qquad (2)$$

where E is Young's modulus and σ Poisson's ratio of the rubber. If the hysteresis loss factor at constant speeds of deformation is constant, the rolling friction should be proportional to $W^{4/3}$. Typical results for a steel ball rolling on rubber specimens of the same Young's modulus but of hysteresis loss factors differing by a factor of 8 are shown in Figure 4. It is seen that F is proportional to $W^{1.3}$, and that the rolling friction for one rubber is about 8 times larger than for the other.

*In this paper we define the elastic hysteresis loss factor as the energy lost through hysteresis divided by the total input elastic energy.

These experiments were extended to the rolling of a steel sphere in a preformed rubber groove. In this case it may be shown that the elastic input energy is almost exactly the same as for a sphere rolling on a flat specimen. The strains will be different but, since the hysteresis loss factor for rubber is independent of the strain, the rolling resistance should be approximately the same. Direct measurements show that this is so. If the grooves are not too deep, the rolling friction for the flat and for the grooved surface is roughly equal.

If the grooves are deep, however, the rolling friction is considerably greater than that due to the hysteresis losses alone. Under these conditions a lubricant can produce a marked diminution in the rolling friction. It is evident that here an additional factor associated with interfacial friction is involved. This is discussed in the following section.

DIFFERENTIAL SLIP IN ROLLING (HEATHCOTE SLIP)

When a ball rolls in a groove there is another possible source of frictional loss which does not apply to cylindrical rolling (Figure 5). The portion of the ball at the center of the region of contact measures out its full circumference (π.AB) in a single revolution, while a portion at the edge of the groove measures out a smaller circumference of length (π.CD). Unless there is sufficient differential stretching of the surface elements of the groove to accommodate this difference, slipping within the ellipse of contact must occur. This was first pointed out by Heathcote[12] but no quantitative estimate of the forces involved was made. It is possible, however, using a very simple analysis[9] to determine the force F that must be applied to the ball to overcome the interfacial friction and so allow rolling to take place, in terms of the track width d and the coefficient of friction μ in the differential slipping process. A more detailed analysis by Eldredge[5] gives a similar but more accurate result

$$F = \frac{\mu W}{12}\left(\frac{d}{D}\right)^2 \qquad (3)$$

For a ball rolling in a groove of nominally its own curvature, the friction due to this factor is appreciable when d/D is greater than 0.8—that is, when the groove is very deep. Assuming that the rolling friction (over and above the hysteresis losses) is due to differential slip, Equation 3 may be applied, and it is then found that μ has a value of about 1. At this stage, as mentioned above, a lubricant produces a marked diminution in the rolling friction and use of Equation 3 shows that this corresponds to a reduction in μ to about $\mu = 0.3$. For shallower grooves the effective value of μ arising from the Heathcote mechanism appears to fall off rapidly. Even for a value of $d/D = 0.4$, the differential slip term for unlubricated surfaces corresponds to a value of μ less than 0.2. This means that only a small part of the theoretical Heathcote term is observed. There is evidence to show that, to some extent, this is due to differential stretching of the elements of the rubber within the ellipse of contact. It is clear that differential slipping of the type described may, under extreme conditions, be important, but that caution must be exercised in applying the Heathcote mechanism quantitatively.

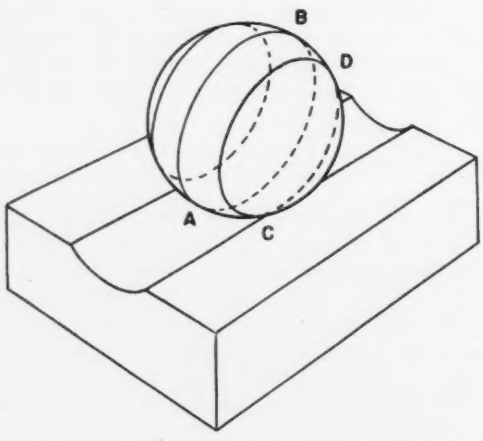


Figure 5. Rolling of a sphere in a groove. For each revolution of the sphere the central band measures out a distance $\pi.AB$. The outer band measures out a smaller distance $\pi.CD$, implying interfacial slip within the ellipse of contact.

ROLLING OF A STEEL SPHERE IN A METAL GROOVE

Consider now the frictional mechanism involved when a steel sphere rolls in the equilibrium track formed in a metal surface. If the major part of the rolling resistance is due to differential slip, F will be given by Equation 3. Since under elastic conditions d is proportional to $(WD)^{1/3}$, this becomes

$$F = \frac{k\mu W^{5/3}}{D^{4/3}} \qquad (4)$$

This is close to the observed empirical relation given in Equation 1.

There are, however, two major difficulties in attributing the rolling friction to differential slip. First, the rolling friction is scarcely affected by the presence of a good boundary lubricant, since clean surfaces and lubricated surfaces give essentially the same rolling resistance. Secondly, the values of μ that must be inserted to give agreement with Equation 4 are exceptionally high, often of the order $\mu = 2$. In ordinary sliding experiments, the boundary lubricants used give coefficients of friction of the order $\mu = 0.05$ to 0.1. The fact that good lubricants produce no reduction in F, and that such high values of μ must be involved, is a strong argument against the view that the rolling friction arises primarily from differential slip.

If the rolling resistance is attributed primarily to hysteresis losses, the elastic input energy per centimeter of rolling (ϕ) is given by a relation similar to that given in Equation 2. If the hysteresis loss factor is a, the rolling friction F may be put equal to $a\,\phi$.

$$F = a\phi \qquad (5)$$

Using the observed values of F, the corresponding values of a may be calculated. The calculations show that a is not a constant for any one metal but increases with the strain. This is in agreement with other observations that the hysteresis losses of metals increase rapidly with strain. However, the actual values of a appear to be impossibly high, of the order of 20% or more for copper and mild steel. It seems desirable, therefore, to determine a by another method that will simulate as closely as possible the deformation processes involved in rolling but which will ensure complete absence of interfacial slip.

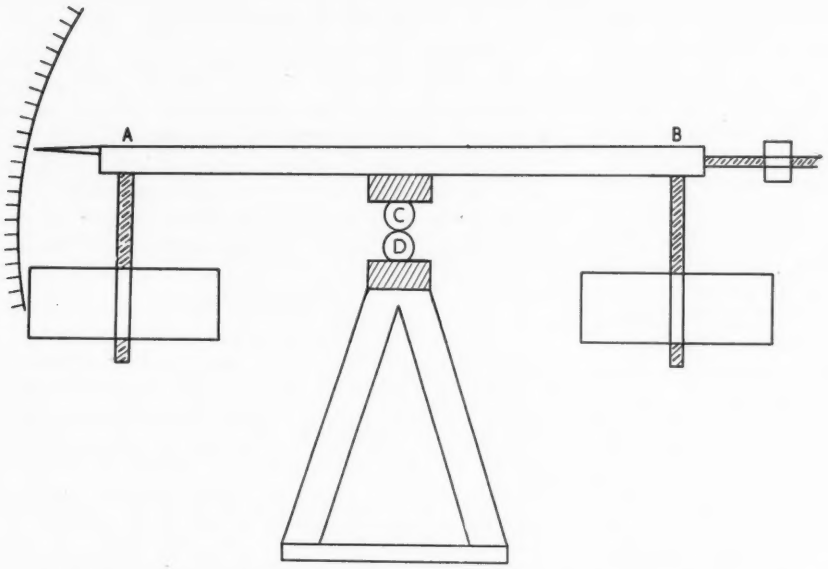


Figure 6. Pendulum apparatus used for determining rolling friction between spheres on spheres. In this arrangement there is no Heathcote slip at the interface.

Fortunately, there is a relatively simple method available for doing this based on an earlier suggestion of Tomlinson's.[13] If a metal ball is rolled over another metal ball of the same material and of the same diameter, the surface of contact must, by symmetry, be plane. Consequently no differential slip of the Heathcote type will occur. Further, any lateral extension or compression of the surface elements at the interface will be identical for both spheres so that no slip of the Reynolds type can take place. It is evident, of course, that the strains will not be the same as for those involved when a hard steel sphere rolls in a metal groove and, since with metals the hysteresis losses depend markedly on the strain, an exact correlation of the two processes cannot be expected. However, the main point is to see to what extent the rolling friction is changed when interfacial slip is eliminated.

ROLLING OF SPHERES ON SPHERES

The rolling of spheres on spheres has been examined in a pendulum apparatus shown in Figure 6. A rigid beam (AB) holds two identical metal balls (C) fixed exactly 3 in. apart (in this figure behind one another), and these roll over two identical metal balls (D) located exactly 3 in. apart and fixed rigidly to the base of the apparatus. The damping of the pendulum is a measure of the couple resisting rolling. By working at long periods of swing, the damping due to the air may be made small compared with the damping due to rolling friction. As a check, an experiment was carried out in which the upper balls were made of hard steel and the lower balls replaced by flat copper blocks. The rolling friction deduced from the damping experiments agreed closely with the values observed directly in Eldredge's apparatus.

In the rolling of metal spheres on metal spheres it is found that the rolling friction is high for the first few swings, corresponding to some initial plastic deformation. After about fifty swings it settles down to a steady constant value, corresponding to an equilibrium stage in which the deformations are essentially elastic. As is to be expected, the rolling friction is not affected noticeably by the presence of lubricants. However, the pendulum is far more stable in the absence of lubricants, and for this reason most of the meaurements were made with degreased surfaces.

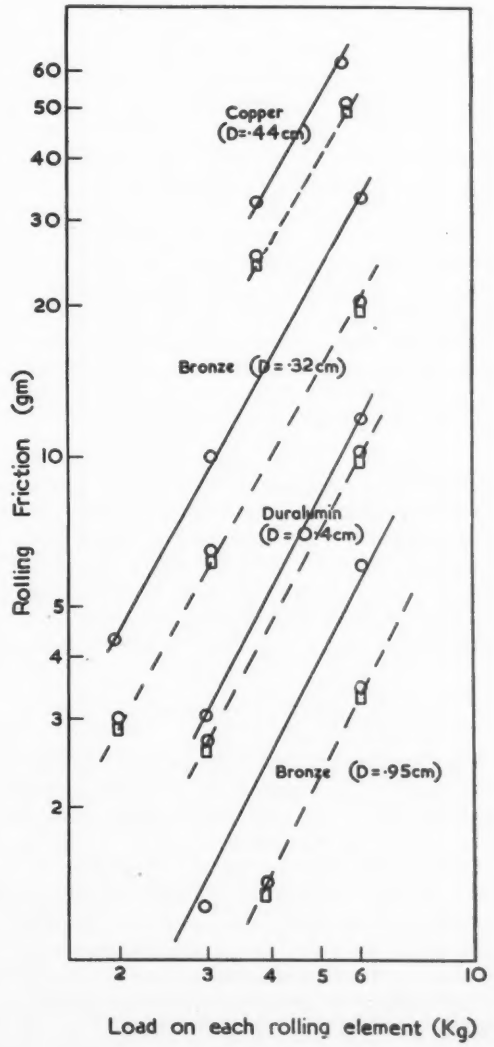


Figure 7. Equilibrium rolling friction for spheres on identical spheres (o) compared with results for hard steel spheres of the same diameter rolling on flat specimens of softer metals. The behaviour is similar, but in the first case where interfacial slip is practically eliminated the rolling resistance is consistently greater by a factor of about 1.6. This shows that interfacial slip is relatively unimportant compared with the hysteresis losses.

The first and most striking observation is that the rolling friction F is roughly proportional to $W^{1.8}$ and to $D^{-1.6}$—that is, the dependence on load and ball diameter is essentially the same as for a steel ball rolling in the equilibrium groove of the metal. The second striking result is conveyed by the results of Figure 7, which compares the rolling friction of a copper ball on a similar copper ball of diameter $D = 0.44$ cm, with the rolling friction of a hard steel ball ($D = 0.44$ cm) on the equilibrium track formed on the flat surface of the same copper. In the first case the two balls are equally deformed; in the second case, only one copper surface is deformed and losses in the harder steel sphere may be neglected. If the rolling resistance is due primarily to hysteresis losses, the friction in the first case should be roughly twice that observed in the second case. If, on the other hand, the rolling friction is due mainly to interfacial slip, it should be negligible in the first case, compared with the second. The results in Figure 6 show that at any given load the friction in the first case is about 1.6 times as great as in the second. It is evident that deformation losses are the primary source of the rolling resistance in both cases.

An analysis of the results obtained with a sphere rolling on a similar sphere shows that, for copper, hysteresis losses of the order of 20% or more occur. Thus, the high losses which seemed a dubious point in explaining the mechanism of rolling friction are seen to have physical validity. These high losses are observed only when appreciable plastic deformation precedes the equilibrium stage, and they are probably accompanied by a small amount of permanent set. In addition, since the specimens are polycrystalline, some of the crystals will be subjected to tensile as well as compressive stresses during the rolling process. This allows the Bauschinger effect to appear, and it is well known that under these conditions very large losses are possible. With harder materials where the stresses are closer to the elastic limit, the losses are very much smaller. Under comparable conditions of W and D, the loss factor is about 10% for phosphor bronze, 5% for Duralumin, and only 1% for ball race steel.

It is convenient to assume that, in the load range examined, the hysteresis loss factor a is proportional to $(\text{strain})^p$. Since the strain is proportional to $(W/D^2)^{1/3}$, this means that a is proportional to $(W/D^2)^{p/3}$. Using Equations 2 and 5, a value of p may be chosen in the final equation for F to give an index of W between 1.7 and 1.85 and an index of D between −1.5 and −1.7. A reasonable choice for p is 3/2 which then yields the relation.

$$F = \frac{k\,W^{11/6}}{D^{5/3}} \qquad (6)$$

Thus the hysteresis mechanism explains the observed rolling behavior if it is assumed that the losses are proportional to $(\text{strain})^{3/2}$. At appreciably lower strains, the losses vary less rapidly with strain, and there is evidence that at low strains the losses are almost independent of strain, i.e. $p = o$ and a is a constant.[14] Under these conditions F is proportional to $W^{4/3}$. It is probable that ball bearings operate in this range, and it is interesting to note that a constant hysteresis loss factor of about ½% would account for a coefficient of friction in a typical ball bearing of about 0.001.

SURFACE INTERACTION

Although interfacial slip appears to play a trivial part in the rolling resistance, this does not mean that surface interaction does not occur during rolling or that it is not important. Radioactive pick-up measurements have been carried out on copper surfaces. The experiments show that for unlubricated surfaces, the pick up was extremely small. In the presence of oleic acid the rolling friction was unchanged, but the amount of copper transferred to the balls was reduced by a factor of over 4.

CONCLUSIONS

The study described in this paper shows that, in "free" rolling, the rolling resistance is due primarily to deformation losses in the solids: in the elastic range, these losses may be identified with the elastic hysteresis properties of the materials. Interfacial effects play a trivial part, and for this reason boundary lubricants produce no detectable diminution in the rolling resistance; however, they may appreciably reduce the amount of transfer or attrition.

Although the behavior of practical ball and roller bearings is complicated by many other factors, elastic hysteresis losses must play an important part. For example, if surface attrition is sufficiently reduced, ball-bearings have been observed to fail by sub-surface fatigue.[15] Similarly, excessive loading or an oversize ball may accelerate fatigue to a marked degree. Although these factors are closely allied to the hysteresis process and have been widely recognized in ball bearing practice, the origin of the rolling resistance itself has long been a matter of speculation. It has variously been ascribed to rolling "up-hill" out of the ellipse of contact, to continuous plastic deformation,[16] to differential slip, [9, 12] and to interfacial adhesive forces.[13] The present investigation suggests that in free rolling on metal surfaces exposed to the atmosphere there is almost no "friction" in the conventional sense of the word. The primary source of the rolling resistance is elastic hysteresis losses in the metals themselves.

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COMMENTARY

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Dr. Tabor's paper contains interesting information and viewpoints. He seems, however, to assert that no one previously has observed the elastic hysteresis resistance due to rolling. I therefore refer to my book "Ball and Roller Bearing Engineering" (Philadelphia 1945) in which I discussed the nature of rolling resistance and mentioned the elastic hysteresis effect as the first point of discussion. Since then this question has been carefully treated theoretically and experimentally. An abstract of the results was presented by me at a friction and lubrication meeting in Darmstadt, Germany, on the 22nd of March 1956, which will be published soon by VDI.

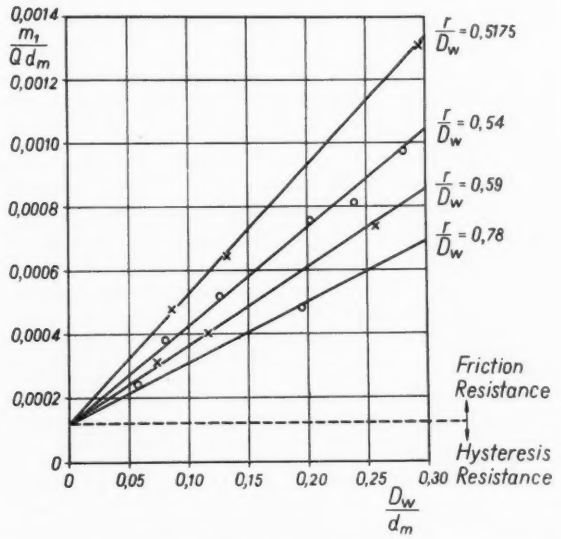

Figure 1. Running resistance of thrust ball bearings with different relative pitch diameters d_m/D_w and different relative groove radii r/D_w, D_w being the ball diameter.

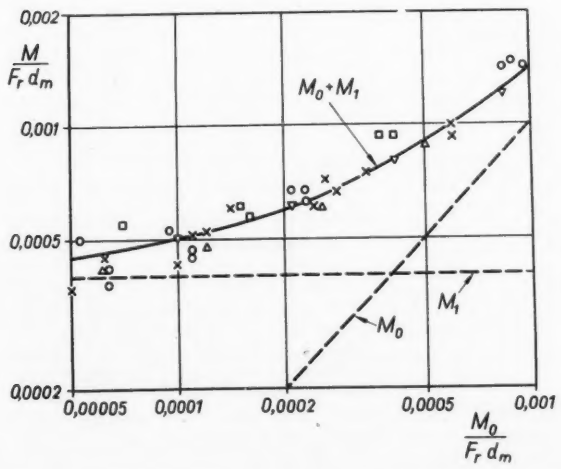

Figure 2. Total running resistance of spherical roller bearings of different sizes at different loads and speeds, F_r being the radial load.

As far as the condition in ball and roller bearings is concerned, Dr. Tabor seems to exaggerate the importance of the elastic hysteresis loss. According to my observations, the resistance to rolling in ball and roller bearings occurs in the following manner:

At small loads and high speeds, the lubricant forms an oil film between the rolling bodies and the races. This phenomenon follows the hydrodynamic laws and makes a resistance because the oil pressure in the front part of the rolling contact is greater than in the rear part.

At moderate or low speeds and increasing load, the oil film thickness is reduced until the surface roughness prevents the formation of a hydrodynamic film. Instead, the molecular properties of the adsorbed layer are deciding, not the viscosity. Under such conditions, deviations from true rolling cause partial sliding within the contact area and frictional forces counteracting the rolling motion. The coefficient of friction is then constant at about 0.06.

Under all loads an elastic hysteresis loss occurs. The hysteresis loss factor is a material constant.

Friction and hysteresis losses occur simultaneously and must be separated if they are to be determined experimentally. This is possible in thrust ball bearings, where both types of losses vary with 4/3 power of the load. The friction resistance in such a bearing depends on the degree of osculation, but is independent of the pitch diameter. The hysteresis loss depends on the pitch diameter, but is practically independent of the osculation.

Figure 1 shows the results of some tests . The hysteresis loss factor is found to have a value of about 1% as predicted by Dr. Tabor, but the friction loss is considerably greater in most cases than the hysteresis loss.

Each one of the rolling resistance components mentioned have been determined theoretically and experimentally. In running anti-friction bearings, they may occur simultaneously. The total energy loss may be calculated as the sum of a term M_0, expressing hydrodynamic losses when running under no load, and a term M_1, containing frictional and hysteresis losses when running under load. An experimental confirmation of this is given in Figure 2. The dotted lines represent the theoretically calculated terms M_0 and M_1 for spherical roller bearings. The continuous line is the sum of these terms. The marked points represent measured resistance in spherical roller bearings of different sizes running with different loads and speeds. Which type of resistance is dominating depends on the bearing design and the running conditions.

AUTHOR'S CLOSURE

I am very glad to have Dr. Palmgren's valuable contribution and to take this opportunity of publicly repairing a serious omission in my references to previous work on rolling friction. Dr. Palmgren's work was known to me only from abstracts in other publications, and I very much regret that I did not make myself familiar with his studies at first hand.

In the book to which Dr. Palmgren refers, which I have now seen, he discusses in six pages the possible causes of rolling friction in bearings and groups them as arising from elastic properties (i.e. hysteresis), interfacial slip, and the resistance of the lubricant. I feel it is only fair to my own work to point out that he does not indicate quantitatively the relative importance of these factors. Furthermore, in later chapters where he discusses the elastic deformation of the rolling elements, he nowhere derives a relation for the elastic work of rolling. As far as I know, this was first given by me briefly in 1952 in the *Philosophical Magazine,* and more fully in 1955 in the *British Journal of Applied Physics.*

The work which my paper described was not, initially, aimed at explaining the action of real ball bearings but at elucidating the basic mechanism of rolling friction when the rolling element travels along a straight track. In explaining our experimental results, we considered the factor of interfacial slip (the Heathcote slip), derived a relation for its magnitude, and showed that it was of minor importance. From measurements carried out where interfacial slip was eliminated, we showed that under our experimental conditions the major part of the friction was due to hysteresis

losses.

Dr. Palmgren has now applied these ideas to the performance of practical bearings and in Figure 1 has given results obtained on a thrust bearing. From the results given in this figure, he concludes that friction due to interfacial slip is, in general, appreciably larger than the hysteresis loss. If I have understood Dr. Palmgren's data correctly, he has considered the skidding which arises when a ball rolls round a curved track: this skidding arises since the outer edge of the ellipse of contact has to travel a greater distance than the inner edge and some spinning of the ball must occur. This gives a frictional loss proportional to $W^{4/3}$ in contrast to the Heathcote loss which is proportional to $W^{5/3}$. It is clear that on this mechanism the smaller the pitch ratio (higher D_w/d_m), the more marked is the spinning and the larger the skid-friction contribution. This is observed. The larger the pitch ratio (smaller D_w/d_m) the smaller the effect, and for $D_w/d_m = 0$ the grooved track becomes linear. It is most encouraging to me to note that at this stage, which corresponds to the conditions of my experiments, Dr. Palmgren's own results show that the friction is due only to hysteresis losses. This means that the Heathcote slip of a ball in a straight groove appears to contribute a negligible amount to the rolling resistance, a conclusion completely in accord with the results of my paper.

It is, of course, true that I have over-emphasized the importance of hysteresis losses and that, as Dr. Palmgren points out, the detailed behavior will depend on the bearing design and on the materials. With very hard ballrace steels, the hysteresis losses will be smaller than for the softer metals I have examined, and the skid term (whatever its source) may become more important. Nearly all the published fundamental work on the mechanism of rolling friction (Reynolds, Heathcote, Tomlinson) has attributed the rolling friction to interfacial effects, and my main purpose is to draw attention to the hysteresis-loss factor. This is not only closely bound up with the fatigue properties of the bearings, it may become of very great importance as a major source of friction even with conventional ball-race steels if ball bearings are run at higher speeds and loads and, particularly, if the operating temperatures are high, since the hysteresis losses increase rapidly with rising temperature.

In conclusion, may I say that I regard Dr. Palmgren's contribution not as contradicting the conclusions in my paper, but as constituting a valuable extension of these ideas to real bearings.

Lubrication Abstracts

(This is the eighth in a series of abstracts of translations of Foreign articles on lubrication, by Henry Brutcher. Copies of the full translations are available, at the indicated prices, by writing Mr. Brutcher at P. O. Box 157, Altadena, Calif.)

Nature of Effect of Phosphate Coating in the Cold Forming of Iron & Steel, by A. Wustefeld & L. Louwien; "Metallwirtschaft," Vol. 21, 1942, pp. 7-14; 33 figs., 2900 words. Study of relations among phosphate coating, lubricant, and cold shaping of steel. Investigation of forming properties of phosphate coatings: How to take and to evaluate prints taken of phosphate coatings. Chemistry of phosphate coating based on reaction with sodium hydroxide solution. Chemical interaction between phosphate coating and lubricant, especially soap (neutral, alkaline, and acid types). Relationship between surface area and adsorption of fatty acid. Size of phosphate crystals as function of surface roughness of basis metal. Nature of lubricating action of soap. Soap vs. straight mineral oils in cold shaping. Importance of time of "soaking" of phosphated parts in lubricant preparatory to deep drawing and pressing operations. (Order No. 1373, price $4.20)

Phosphate Coating as Aid in Cold Drawing, by H. Faber & H. Kopp; "Korrosion & Metallschutz," Vol. 17, 1942, pp. 3-11; 2 figs., 2200 words. Advantages of phosphate coating for cold shaping, especially for cold drawing of steel. The so-called draw-bonderizing process (German Patent No. 673,405) described on the basis of a practical example (cold drawing of tubes). Sequence of steps; correlation between coat thickness and drawing operation; elimination of friction, etc. Advantages of process: Nearly complete elimination of process anneals (plus subsequent pickling operations) and resulting production delays; reduction of number and size of furnaces, pickling tanks, etc.; lower metal losses from scaling and pickling; huge increase in service life of drawing or pressing tools (savings on tool cost, labor cost for dressing them, and reduction of stoppages at plant), drawing benches, presses, etc., and possibilities of stepping up amount of reduction (three instead of five drafts) and drawing speeds; better surface finish. New fields for phosphate coating: The drawing of steel wire and various sectional steels. (Order No. 1569, price $3.30)

Character of Phosphate Coating and Their Behavior in the Cold Drawing of Tube & Bar Stock, by A. Durer & E. Schmid; "Korrosion & Metallschutz," Vol. 20, 1944, pp. 161-164; 14 figs., 4000 words. Technical importance of phosphate coatings in shaping operations. Study of nature of phosphate coatings on basis of Debye powder photograms and wax prints. Technique of wax printing. Experiments on behavior of phosphate coatings in processes of forming, especially in cold drawing. Formation of transparent and tenacious coatings made up of crystal fragments. Role of lubricant. Data on microhardness of phosphate coating crystals. Behavior of lubricant in spongy and opaque vs. smooth and transparent coatings. (Order No. 1705, price $6.00)

Drawing of Wire & Bar Stock Made Easier by Phosphate Coating, by E. Schmid; "Stahl und Eisen," Vol. 62, 1942, pp. 968-972; 15 figs., 3900 words. Nature of beneficial effect of phosphate coating on shaping operations, studied on the basis of precision-drawn tubes. Oil-absorptive capacity of phosphate coating related to its thickness. Permanent deformation of phosphate coatings. General Discussion: Replica technique for microscopic study of phosphate coatings. Soaking in neutral, acid, and alkaline soap solutions and effect of soaking time on phosphate crystals and power requirements in drawing. Phenomena of adsorption; tentative explanation. Plasticity of phosphate coatings. Experimental data on the drawing of phosphate-coated steel wire with oil emulsions and soap powder. Data on usefulness of phosphate coating in the cold drawing of special-section steel bars; elimination of process anneals and acid cleaning operations. (Order No. 1987, price $5.85)

Application of Chlorates as Oxidizers in Phosphating, by F. Rossteutscher; "Korrosion & Metallschutz," Vol. 20, 1944, pp. 165-166; 2 figs., 1900 words. Reaction mechanism of chlorates added to phosphating bath as oxidizing agents. Advantages of their use; thin flexible coatings quickly formed; suitability of coatings for cold drawing operations. (Order 1749, price $2.85)

A Process Facilitating the Drawing of High Alloy Steels, by F. Rossteutscher; "Archiv fur Metallkunde," Vol. 3, 1949, pp. 282-283; 1600 words. Processes occurring in the cold shaping of semifinished steel; tool; role of lubricant. Cold shaping of ordinary steels made easier by phosphate coating. Phosphate coating inapplicable to alloy steels, particularly acid and heat resisting Cr-Ni steels; underlying reasons. Description of an oxalic acid treatment developed by author for such steels to take the place of phosphating; its theory and results obtained with it in commercial practice. (Order 2448, price $2.80)

Concentration Effects of Cutting Oil Additives in Performance Evaluation

Performance tests which included turning, planing, and tapping demonstrated the concentration-dependent activity of additives in cutting oils. The results form the basis of a hypothesis for the mechanism of cutting oil action which involves the temperature-activated reaction of additive with metal. According to this hypothesis, the behavior observed for a particular cutting oil will depend on the relation between wear by metal to metal contact of chip and tool, and wear by chemical reaction of the tool material with the additive.

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In recent years there has been increasing emphasis on evaluation of cutting fluids by laboratory performance tests which involve the cutting of metals under conditions analogous to those expected to be encountered in practical situations. For lack of a usable theory, the experimental approach is empirical, and because of the utilitarian motive for the tests, those results which do not further the commercial exploitation of cutting oils are usually neglected.

In this paper some data from a cutting oil development program will be examined for evidence of systematic relationships between additive concentration and performance, and some preliminary speculations, of a qualitative nature, will be presented on the mechanism of additive action. Data from three different types of machining tests will be scrutinized: (1) single point lathe-tool life, (2) surface finish by orthogonal planing, and (3) tapping torque.

TOOL LIFE & CUTTING OILS

The tool life figures were obtained with high speed steel tools on a 16 × 54 engine lathe equipped with a D.C. motor, rheostat controlled for variable speed drive. The one-half inch square type M-2 tool bits were ground to 8-14-6-6-6-15-3/64 geometry. Depth of cut was 0.100 inch and feed was 0.011 inch per revolution. Cutting fluid was directed over the chip and the face of the tool by downward flow at the rate of 5 gallons per minute from a sump whose temperature was maintained at 100°F. The tool life data for a given test were found to conform to the familiar Taylor relation, which was used in its linear form,

$$\log V + n \log T = \log C \qquad (1)$$

where V is the cutting speed in surface feet per minute, T is the time of cutting in minutes to complete tool failure, n is the slope of the linear relation between $\log V$ and $\log T$, and C is the value of V when $\log T$ equals zero (i.e., the cutting speed for a tool life of one minute).

The cutting oils used for this study are listed in Table I. For each additive type, the lowest concentration employed is designated as the unit concentration, and the concentration ratio for the other oils of the series is given as a multiple of the unit concentration. The level of the active additive elements in the cutting oil can be judged by the figures for percent chlorine and the increase in percent sulfur. In all, six different types of additive were studied.

Table I

Compositions & Characteristics of Cutting Oils

Oil	Additive Ratio	Sulfur, %	Chlorine, %	Viscosity, SUS @ 100°F
A-1	1	0.20	0.05	108
A-2	2	0.25	0.12	108
A-4	4	0.39	0.23	108
B-1	1	0.19	0.05	110
B-2	2	0.25	0.13	110
B-4	4	0.40	0.20	110
C-1	1	0.33	0.12	109
C-2	2	0.59	0.30	112
D-1	1	0.76	0.82	146
D-1.5	1.5	1.05	1.19	161
D-3	3	1.64	2.08	248
E-3	3	0.97	0.63	89
F-1	1	—	4.28	161
F-2	2	—	8.38	121
F-2.5	2.5	—	11.6	135
F-5	5	—	21.1	131

Table II presents data for additive A and for additive B which demonstrate the effect of additive concentration in the cutting oil on tool life. Additive A is a sulfur-chlorinated product prepared from an unsaturated hydrocarbon and a neutral fat; additive B is an analogous sulfur-chlorinated product prepared from an unsaturated hydrocarbon and a fat with free fatty acidity. Expressed in terms of T_{100}, the tool life at 100 s.f.p.m. cutting speed, the effect of the concentration of additive A is beneficial for a rise from unit concentration to a two-fold level, and detrimental for a further rise from the two-fold to the four-fold ratio. This relation is valid for both AISI 4150 and AISI 8640 steels, although the re-

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Table II

Lathe Testing Data for Oils Containing Additives A & B
(See Equation 1 for the meaning of C, T, and n)

Oil	C, s.f.p.m.	T_{100}, Min.	n	$1/n$
	AISI 4150 Steel			
A-1	173	122	0.114	8.77
A-2	175	178	0.108	9.25
A-4	165	90	0.111	9.01
B-1	155	65	0.105	9.52
B-2	150	49	0.104	9.60
B-4	143	27	0.101	9.90
Base Oil	161	68	0.113	8.85
Dry Cut	161	40	0.129	7.75
	AISI 8640 Steel			
A-1	220	4000	0.095	10.53
A-2	224	4860	0.095	10.53
A-4	215	3150	0.095	10.53
Base Oil	206	1380	0.100	10.00
Dry Cut	194	164	0.130	7.68

sponse of the latter to the presence of cutting oil is more sensitive than that of the former. The T_{100} data for additive B, which were obtained only with AISI 4150 steel, show a reverse dependence on concentration as the ratio is changed from unit through two-fold to four-fold.

Interpretation of the data in Table II can be extended beyond the empirical relations between tool life and concentration of additive if three postulates concerning the mechanism of additive action are adopted. Firstly, it will be assumed that the initiating step in the tool wear process is a temperature-dependent interdiffusion of metal across the tool-chip boundary. Diffusion of workpiece material into cemented carbide tools has been demonstrated and studied by Dawihl[1-3] and by Trent.[4] Trigger and Chao,[5] and later Loewen and Shaw,[6] made mathematico-physical analyses of temperature at the chip-tool interface; and Trigger and Chao[7] studied the mechanism of crater wear of carbide tools in relation to the interface temperature. The second assumption is that diffusion is restricted to those asperities of the chip-tool interface which are in actual contact, and that the welding and plucking phenomena which become manifest as gross wear originate at these asperities; consequently, control of diffusion and of welding at the asperities is control of wear. According to Bowden and Tabor,[8] the areas of individual contacting sites in two surfaces rubbing against each other are of the order of 10^{-3} sq.cm. or less, and the friction-induced temperature rise at these sites has a duration of the order of 10^{-4} to 10^{-3} second. The third assumption is that the cutting oil additive functions by chemical reaction with activated metal atoms throughout the chip-tool interface, and that the products of reaction no longer have metallic properties so that diffusion, welding, and plucking at contacting asperities are inhibited.

The data available in the literature[5-6] on the relation between the chip-tool interface temperature and cutting speed can be expressed in an equation of the same form as the Taylor cutting equation,

$$\log\theta - k\log V = \log K \qquad (2)$$

where θ is the interface temperature, k is a constant and $\log K$ is the value of the intercept of the function on the axis of θ. On solving Equation 2 for $\log V$ and substituting in Equation 1, the following relation is obtained:

$$\log\theta + kn\log T = \log K + k\log C \qquad (3)$$

From Equation 3 it can be seen that $-1/(kn) = d\log T/d\log\theta$, i.e. $1/n$ is proportional to the logarithmic temperature coefficient of tool life.

The values of $1/n$ in Table II show that the logarithmic temperature coefficient of tool failure in the presence of cutting oil is higher than for dry cutting. The significance of this behavior is readily interpreted on the assumption that the cutting oil additive reacts with the metal fast enough to inhibit the gross phenomena of wear (welding, plucking) at a temperature appreciably below that at which diffusion becomes rapid. The situation at the chip-tool interface is thought of as a competition between the effects of additive reaction and the effects of the diffusion and welding process. The additive reacts with metal more readily than metal diffuses and welds to the tool at lower temperatures, while at higher temperatures the influence of diffusion and welding becomes more prominent and narrows the difference between tool life in the presence of cutting oil and tool life when cutting dry. The beneficial effects of the cutting oils whose C values lie above the C values for dry cutting are easily explained on this basis. The explanation for the detrimental effect of the additive in those cutting oils whose C values are below that of dry cutting, rests on the assumption that attrition of the tool material by chemical action of the additive is as great as or greater than attrition by the welding and plucking of unlubricated metal. This is the type of concentration-dependent behavior exhibited by additive B. Since the course of tool wear with temperature is the sum of two detrimental influences, the relative proportion of one of which increases much faster with temperature than the other, it is seen that in this case the difference between lubricated cutting and dry cutting becomes greater with increasing temperature. To explain the concentration-dependent behavior of additive A, it will be necessary to postulate that the competition in rate between chemical reaction and diffusion-controlled welding is such that a certain minimum concentration of additive is necessary to counteract the diffusion effect, but that a higher concentration of additive introduces the undesirable effects of excess attrition by chemical reaction.

The behavior of two oils, one containing unit concentration of additive A and the other a like amount of additive B, in the Falex E.P. tester is in line with the hypothecated difference in the modes of action of the two additives. Figure 1 shows the relation between applied jaw load and torque for oils A-1 and B-1 by this test method.

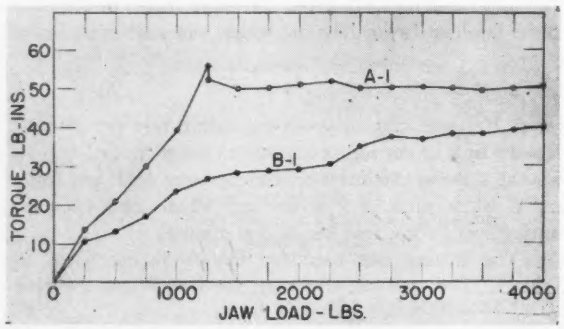

Figure 1. Chemical reactivity of additive A and additive B as differentiated by the Falex test.

With oil B-1, chemically aggravated wear must be taking place from almost the beginning of the test, as indicated by the downward concavity and the rapid levelling off of the torque curve. With oil A-1, however, the normal force relationships of friction are maintained up to an applied load of 1250 pounds, after which the torque curve undergoes a transition to the plateau characteristics of anti-seizure via chemical attrition.

Table III shows some flank wear data which can be related to the differing chemical reactivities of additives A and B. The cutting tests were run on AISI 4150 steel at 60 s.f.p.m. with the same lathe and the same tool geometry used in the tool life tests. The comparisons in Table III are made on the basis of the time rate of increase in the wear land on the flank of the tool; Figure 2 illustrates the reason for this. The upper half of the figure shows a plot of the flank wear values in their original form, just as they were measured on the tool; in the lower half of the figure, the wear curves have been moved toward the abscissa so that they all pass through the origin. Thus the data of Table III emphasize the steady state process of flank wear, while the initial wear is regarded as an accidental factor dependent on the accuracy of tool grinding and tool setting. Consistently, at equivalent concentrations, the greater chemical reactivity of additive B over additive A is shown by the higher rate of flank wear. It is also interesting to note that none of the compounded oils is as effective as the uncompounded base oil in reducing flank wear; and of the compounded oils only A-1 is better than dry cutting. The failure of the flank wear results to correlate completely with the tool life results is probably connected with the better accessibility of the contact area between the workpiece and the flank of the tool to the cutting fluid as compared to the accessibility of the chip-tool boundary; this can be regarded as a strong shift in the concentration effect in the direction of the B additive

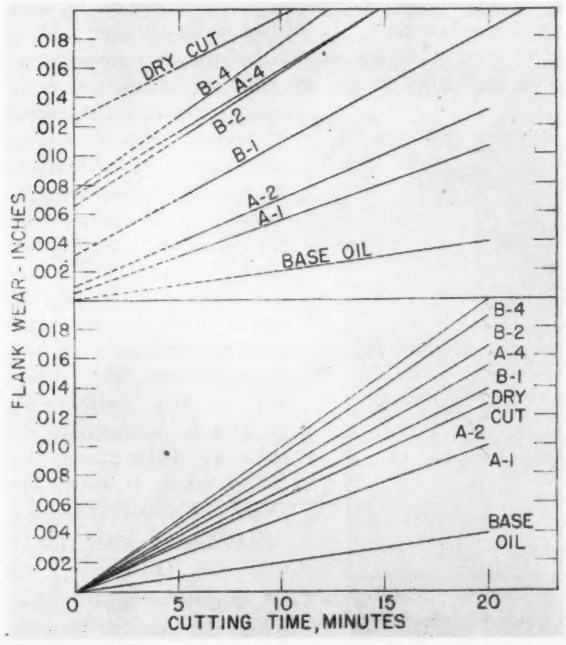

Figure 2. Influence of additives on flank wear.

Table III

Flank Wear with Cutting Oils Containing Additives A & B

Oil	Rate of Flank Wear, Inches Per Minute
A-1	0.000500
A-2	0.000600
A-4	0.000835
B-1	0.000767
B-2	0.000935
B-4	0.001000
Base Oil	0.000200
Dry Cut	0.000665

Determinations made on AISI 4150 steel at 60 s.f.p.m.

Table IV

Lathe Testing Data for Oils Containing Additive C (AISI 4150 Steel)

Oil	C, s.f.p.m.	T_{100}, Min.	n	$1/n$
C-1	180	357	0.100	10.00
C-2	174	241	0.101	9.90
Dry Cut	160	75	0.109	9.18

Table V

Lathe Testing Data for Oils Containing Additives C, D & E (AISI 1141 Steel)

Oil	C, s.f.p.m.	T_{100}, Min.	n	$1/n$
D-1	191	689	0.099	10.10
D-1.5	189	696	0.097	10.30
D-3	193	767	0.099	10.10
E-3	185	470	0.100	10.00
C-1	195	794	0.100	10.00
Dry Cut	176	156	0.112	8.93

type of behavior. Other possible explanations include difference in magnitude of friction force and difference in the state of surface activation at the flank as compared to the chip-tool interface.

Table IV contains tool life data on AISI 4150 steel for two oils compounded with additive C, a sulfur-chlorinated mineral oil. An inverse concentration effect is noted in going from C-1, with unit concentration additive, to C-2, with a two-fold concentration ratio. Comparison of the T_{100} value for the dry cut on this particular workpiece with the T_{100} value for the workpiece in Table II, shows that the former specimen of AISI 4150 steel had the better machinability. This points up one of the most difficult problems in reducing the hypothesis proposed in the present paper to a quantitative theory: how to introduce the parameter for the properties of the material being cut. Although the two pieces of 4150 steel had significantly different hardness (195 BHN for the one, 215 BHN for the other), this does not seem to be the key, since the AISI 8640 steel listed in Table II had a BHN of 192 and a T_{100} value of 164 minutes.

Table V lists tool life data for two additives which contain fatty oil, active sulfur, and a chlorinated compound, additive D having more than three times as much chlorine and active sulfur as additive E. The material cut was AISI 1141 steel. The concentration effect for additive D is negligible on going from unit concentration to a 1.5 concentration ratio, and small on further increase to a three-fold ratio. Additive E, which was used in a concentration ratio equivalent to D-3, gave the poorest value for T_{100}, which might be ascribed to the lower level for chlorine or for active sulfur, or to a combination of both

factors. Included in Table V are data for oil C-1 which show the lack of correlation between the chemical analysis of an oil and its cutting performance. Oil C-1 with 0.33% sulfur and 0.12% chlorine has a somewhat better tool life than oil D-3 with 1.64% sulfur and 2.08% chlorine, which can be interpreted as indicating greater chemical activity for additive C. The value of $1/n$ is of the same order of magnitude for all the oils in Table V, and the beneficial effect of increasing the concentration of additive becomes apparent through the increase in the value of the constant C. This is just the reverse of the behavior exhibited by the oils containing additive B in Table II.

SURFACE FINISH & CUTTING OILS

Additive concentration effects were also observed in the surface finish obtained by an orthogonal cutting test analogous to planing. A tool with 10° rake and 2° clearance was mounted in a special fixture on the arbor support of a milling machine, and the work was carried against the tool at 90 inches per minute by the motor driven table feed making a cut 0.002 inch deep. The setup is similar to that employed by Lauterbach and Ratzel[9] except that a fixed tool holder was used. Surface finish on the workpiece was read in microinches root-mean-square roughness with a Profilometer. Figure 3 shows the results of some surface finish studies carried out with solutions of carbon tetrachloride and of additive F in oil on AISI 4150 and AISI 9310 steels. There is a close parallel between the results for AISI 9310 steel with the oils containing carbon tetrachloride and the results with the oils containing additive F; a slight gap is noted between the two surface finish curves in the region of overlap, but otherwise the one curve seems to be a continuation of the other. This can be taken as an indication of similarity in the chemical reactivity of the two additives. The overlap regions of the two surface finish curves for AISI 4150 steel do not show such close parallelism, but on the other hand they are not strongly divergent.

Additive F is dibutyl chlorendate (U. S. Patent pending), a non-volatile, non-toxic, highly chlorinated ester. Its use was developed as part of a program to match the metal working properties of carbon tetrachloride without its undesirable volatility and toxicity. Another chlorinated substance whose concentration-dependent effect seems to be in the same category is a dichloride derived from diisobutylene. The one concentration of this additive investigated fits well on the performance curve in Figure 3 for AISI 9310 steel, and is not far removed from the curve for AISI 4150 steel. On the other hand, the performance of chlorinated wax on AISI 9310 steel as shown in Figure 3 does not match the curve drawn there, which indicates lower reactivity of the chlorine in chlorinated wax.

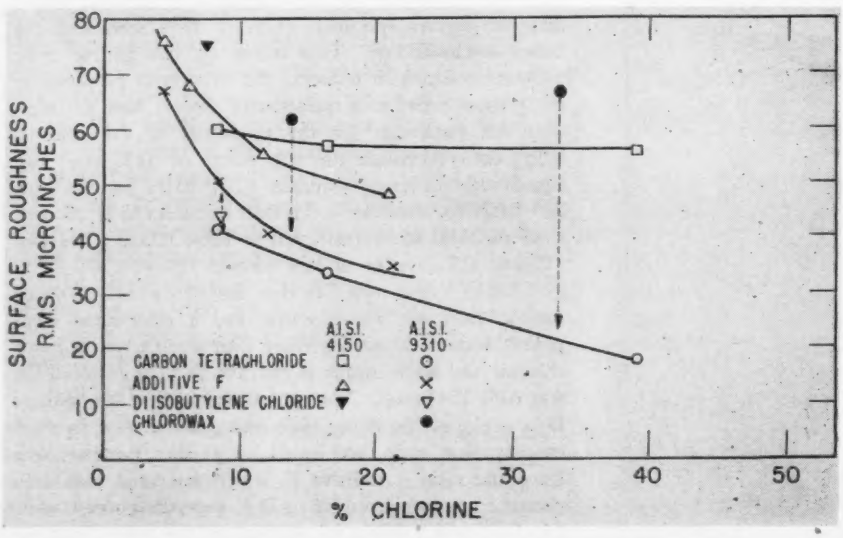

Figure 3. Concentration effects of chlorinated additives on surface finish.

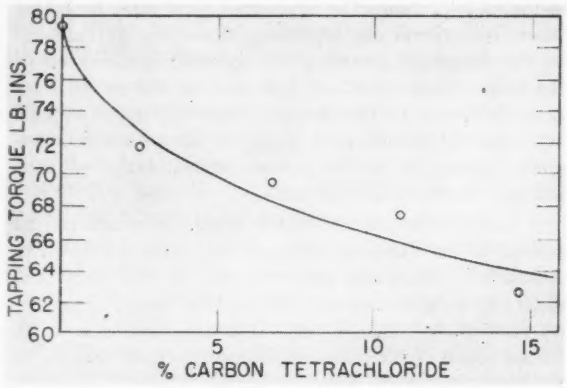

Figure 4. Effect of concentration of carbon tetrachloride in oil on tapping torque.

The hypothesis advanced to explain the effect of cutting oil additives on tool life can be extended to include surface finish effects. According to Ernst and Merchant,[10] good surface finish depends on the minimization of the built-up edge on the cutting tool. Now the formation of the built-up edge is a welding phenomenon and, as such, should be controllable by the chemical action of the additive. As long as the concentration-governed rate of reaction of additive with metal is insufficient to suppress welding substantially, the surface finish obtained with a given type of cutting oil will be strongly concentration-dependent. But as the concentration of additive more nearly approaches the level of maximum effectiveness, the sensitivity of surface finish to increase in concentration diminishes, as is illustrated by the curves in Figure 3. The level of maximum effectiveness depends on the chemical nature of the additive; certain additives have similar concentration-dependent properties (carbon tetrachloride, additive F, diisobutylene dichloride), while the reactivity of others is much less (e.g., chlorinated wax).

TAPPING & CUTTING OILS

Figure 4, which illustrates the relation between the concentration of carbon tetrachloride in oil and the

torque when tapping holes in AISI 1055 steel, follows a pattern quite similar to that observed in Figure 3; initially, there is a strong concentration-dependent effect which drops off rapidly with increasing concentration of carbon tetrachloride in the oil. The torque value shown for each concentration is the average of twenty successive holes with the same tap. There is a slight rise in torque from the first to the twentieth hole, indicative of progressive tap wear. Figure 5, which is a record of the tapping torque hole by hole for pure redistilled carbon tetrachloride and two representative oil solutions, shows in a striking fashion the results of wear due to excessive chemical activity. The torque for the first hole tapped with carbon tetrachloride was the lowest of any in the entire study, but for each suceeding hole tapped the torque rose rapidly, until by the time the eleventh hole was tapped the torque exceeded that observed with the uncompounded base oil.

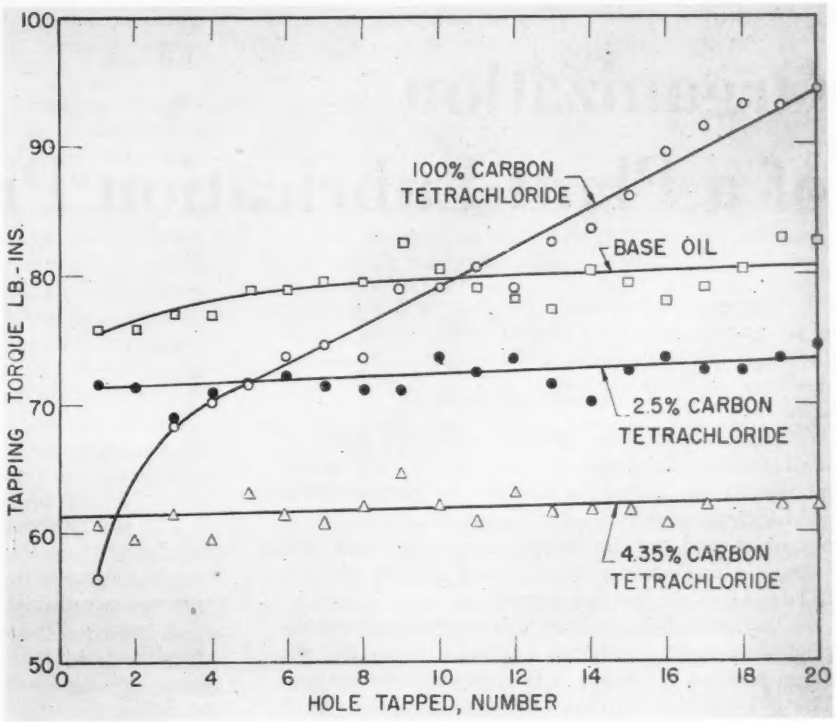

Figure 5. Progressive wear during the use of carbon tetrachloride in tapping oils.

SUMMARY

To summarize, the chemical factors in cutting oil action have been examined in relation to single point lathe turning, orthogonal planing, tapping, and E.P. bench testing. Qualitatively, the picture has been fairly consistent. The concentration-dependent effect of cutting oil additives on performance test results point to the necessity of careful quantitative study for a better understanding of the mechanisms by which they operate. The fundamental physics of metal cutting has made great progress in this direction, and it is to be hoped that the chemistry of additive action will soon follow suit.

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Of Special Interest:

Professor George Hugel, Head of the French Institute of Petroleum, Paris, will present his paper entitled "Chemical Nature of Extreme-Pressure Lubricants" at the **12th ASLE Annual Meeting & Exhibit,** April 15-16-17, 1957, Hotel Sheraton-Cadillac Hotel, Detroit.

Organization of a Plant Lubrication Program-III

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Progressive management recognizes the importance of an organized lubrication program which assures, through the proper type and application of lubricants, the minimum downtime on equipment and a reduction in maintenance costs.

These economies are effected through the efforts of the Lubrication Supervisor who sees that superior quality lubricants are used, that the lubricants are properly stored and handled, that there is adequate and efficient dispensing equipment, and that his competently trained crew will service the equipment with the correct amount and type of lubricant at the specified intervals.

The heart of the program is the competency and dependability of the lubrication mechanics, which in large measure reflects the degree of training they have received. This training takes the form of films on the principles of lubrication, lectures on plant practices with examples of lubrication failures, and reviews of lubricant specifications and plant schedules.

The work of the lubrication group is simplified by providing schedules and routes, reducing the number of lubricants to a minimum, and establishing plant code numbers to identify types and grades of lubricants.

LUBRICATION ECONOMIES

With competition in all fields as keen as it is today, any sound method of lowering the unit cost of a product becomes an important factor in plant operations. An organized lubrication program will contribute greatly in reducing this unit cost by helping to maintain efficient operation of the equipment for a greater percentage of the time.

These economies are effected through the efforts of the Lubrication Supervisor who sees that superior quality lubricants are used, that the lubricants are properly stored and handled, that there is adequate and efficient dispensing equipment, and that his competently-trained crew will service the equipment with the correct amount and type of lubricant at the specified times.

Additional savings are realized by cutting down on the number of required lubricants stocked, thus reducing inventories and eliminating special high priced lubricants. For example, our plant is now using one multi-purpose grease for all grease-lubricated bearings, where formerly, before the lubrication program had been inaugurated, there were four different greases doing this job. Now, mechanical failures due to the application of the improper special grease have been eliminated. The greater the number of specialty lubricants the larger is the chance of error in servicing with the wrong lubricant. It was also found that the total yearly grease bill was less with the multi-purpose grease, even though the unit cost was higher, because it was not necessary to service the bearings as often.

The same economies were made with the lubricating oils where the number of oils was reduced by one-half. Some of the new oils were higher priced, but because of their resistance to oxidation they had a longer useful life.

It pays to buy good quality lubricants. With quite a number of our lubricants, we went to a higher quality product and in so doing upped the unit price by 25 percent, but it was found that we had also doubled the life of the lubricant in that particular operation. It is false economy to try to save too much on the price of lubricants at the expense of quality. The lubricant bill is small in comparison to the cost of maintenance repairs if the wrong type or insufficient quantity of lubricant is used.

SUPERVISION RESPONSIBILITIES

All plants, regardless of size, should have the responsibility for equipment lubrication under one supervisor. This supervisor, who may be an engineer or practical man, should have an adequate field training or education in lubrication. Depending on the size of the plant, he may have one or more assistants to direct the activities of the lubrication group. In small plants where a full time Lubrication Supervisor cannot be justified, the responsibility for lubrication should be put in the hands of someone such as the Millwright Foreman as a part time job. It is by coordinating all lubrication activities under one head that the most effective supervision of the program is obtained.

In our plant, where our Lubrication Program is now five years old, the Lubrication Foreman with his crew of 12 men reports to the Assistant Department Head of Maintenance.

FOREMEN

This Foreman is responsible for all lubrication problems in the plant. As well as supervising his men, he also investigates mechanical failures to see if the lubrication is the cause. He also ensures the proper servicing of new equipment installations. Since ours is an around-the-clock operation, lubrication of equipment on nights and weekends is the job of the Maintenance Shift Mechanics. However, the training and scheduling of the lubrication work of these men is the responsibility of the Lubrication Foreman.

The plant is divided into Maintenance Areas with each Area having its own Lubrication Room with complete

dispensing equipment and stock of required lubricants with the necessary number of men to service the equipment in the Area.

A good working knowledge of the physical properties, specifications, and service limitations of lubricants is an important requisite for the Lubrication Supervisor. With this information, it will be easier for him to diagnose lubrication failures and make special recommendations on equipment which presents a potential lubrication problem. In one case we had a failure on a large two roll mill sleeve bearing. These bearings were lubricated with a circulating oil system using an SAE 140 paraffin-base oil containing rust and oxidation additives. After operating for several years on continuous service with no trouble, the oil supply to one bearing was inadvertently cut off, and there was excessive wear of the bronze sleeve bearing and the possibility of a pitted roll neck. Because of the excessive wear, it was believed that there was insufficient bearing area left to hold an adequate film of the present lubricant. Even though bearing temperatures were around 300° F., it was decided to use an extreme pressure lubricant to keep this unit running. By keeping a good flow of oil to the bearing, the roll neck and bearing were lapped in, and this bearing has now run almost continuously for over a year without any further trouble. The production unit was kept running, and the cost of an overhaul was saved because the Lubrication Supervisor was thoroughly informed as to what his different lubricants could do.

Lubricant Evaluation

Another important phase of the Lubrication Supervisor's job is the testing of new lubricants. It is necessary for him to keep in touch with oil company representatives so that he can follow the latest technical developments in lubricants and, as improved formulations are recommended to him, run field tests on them.

In our plant, all new lubricants are given a thorough field test on one piece of equipment under our most severe operating conditions before they are released for plant use. Prior to testing a new lubricant, the system is generally dismantled and thoroughly cleaned. Under normal conditions, a period of from six months to one year of continuous operation is considered as adequate time for a field test. If the result of the test is acceptable, the lubricant is then used throughout the immediate Maintenance Area. After another successful six months as an Area lubricant, it is then released for general plant use.

The situation is somewhat different when we are faced with a lubrication failure because the present lubricant will no longer carry the load. This often happens when an additional load is put on equipment. All available sources are then consulted, and the lubricant with the best performance data is selected for use.

PERSONNEL

Operating personnel in many cases have little concern or understanding of the detailed problems which are involved in lubrication. The viscosity, grade of oil, or rate of flow means little to them as long as they can see something go by the sight glass. One of the responsibilities of the Lubrication Supervisor has been to make these people aware of the problems and tell them what we are trying to do to prolong equipment life. Such training is one of the most vital activities of the Supervisor. The program should be designed to impress upon the men the importance of the lubrication program. Through it, they should acquire a keen interest in their work and be convinced that their job is an important one. If they are indifferent or careless, the equipment will suffer.

Even where there is a sound scheduling system, it is possible for a lubrication man to under or over-lubricate. This may not cause an immediate failure of the bearing, but it might considerably shorten its normal life. If the morale of the lubrication group is high, it is a good indicator that the equipment is being serviced efficiently.

The lubrication mechanics should have a good mechanical background and be completely familiar with the maintenance problems of the equipment they are servicing. The better mechanical training they have had, the better the job they can do.

Training Aids

Even with well trained mechanics, it is necessary to provide additional training in the fundamentals of lubrication. This can be accomplished best by such visual aids as motion pictures and slides on the subject. These are generally obtained from oil companies and such government agencies as the Bureau of Mines. They do an excellent job of graphically portraying the principles of sliding friction, film strength, viscosity, and oxidation.

Another means of training is to take a series of parts that have failed in service, such as ball and sleeve bearings, gears, chains, sprockets and explain the reasons behind their failure. These practical demonstrations are an effective means of impressing upon the men the costly damage to equipment when there is careless lubrication or maintenance.

Maintenance

Since lubrication ties in so closely with many maintenance operations, it is important that all Maintenance Foremen concerned with the overhaul of equipment should attend these meetings along with the Lubrication Group. A sleeve bearing with a grease groove cut the wrong way can make the Lubrication Supervisor's problem a difficult one. Also, dirt which is introduced into a ball or roller bearing during assembly will considerably shorten the life of the bearing, and the early failure will bring some unwarranted criticism on the lubrication mechanic for not having serviced it properly. Thus, the establishment of sound lubrication practices is not only the job of the Lubrication Supervisor. He requires the cooperation of Maintenance Formen as well.

The lubrication mechanics play an important role in the preventive maintenance program. By checking regularly on the major pieces of equipment, they are in a position to detect such deficiencies as noisy bearings, excessive vibration, loose guards, and misalignment of gears. These should be reported immediately to the Lubrication Supervisor who will take immediate steps to have them corrected. For this reason, too, it is important that the mechanics have a good mechanical background.

The lubricant coding system and specifications, as well as the schedules, routes, and frequency of servicing should be periodically reviewed with the group so that all of this is clear in the minds of the men.

SCHEDULING AND CLASSIFICATION

Lubrication schedules for the plant should be set down in a Plant Lubrication Manual. In this manual there should be listed, by departments, each piece of equipment with the specific parts to be lubricated. The lubricant required and the frequency of servicing should also be recorded. Each lubricant is specified by code number as this avoids the confusion of brand names among the lubrication mechanics. The oils have one set of code numbers and the greases have another. The oils are given the code letters *LO* with a number following designating grade and quality, while greases use the code letters *LG* with a number following also designating grade and quality. These code letters are stenciled on the top and side of each drum. For example, *LO-1* is a turbine quality oil of SAE 10 viscosity. The same designation *LO-1* will apply for all brands of this turbine quality oil which meet these specifications and are included in the Lubrication Department's Approved List of Lubricants.

On the Approved List there are two classifications of lubricants. One consists of the brand names of lubricants which have been tested and accepted, and the other classification holds those lubricants which meet the plant lubricant specifications but have not been tested. The Purchasing Department buys only those lubricants which have been tested and accepted. If for some reason the Purchasing Department wants to buy a brand which is on the list but not tested, it will first have to be given a field test.

As part of the Lubrication Manual, there is a section on lubricant changes in closed and circulating oil systems. Any oil which is not in a run-through type system has to be changed periodically. In a record of lubricant changes, it is noted whether the oil was changed or filtered and whether the system was flushed or the reservoir dismantled and cleaned. The record is kept by a clerk in the Maintenance Office.

The frequency of lubrication service on the various pieces of equipment has been decided after much trial and error. Operating temperatures and load conditions are important factors in determining the time between applications or checks on the level of the lubricant in the system. The time specified for frequency of service means continuous operating time. Each area lubrication mechanic is responsible for knowing what equipment is operating in his area, and if a piece of machinery has to be greased monthly and has been idle for two weeks of the month the actual time between lubricant applications will be six weeks.

STORING AND HANDLING

All the time and effort put into the proper selection of lubricants is voided if there is not the proper storage and handling of lubricants. A small amount of foreign matter introduced into the lubricant because of careless handling or storage may result in severe damage to equipment, particularly if the application is in ball or roller bearings where there are honed bearing surfaces. It is of utmost importance that the lubricant be delivered from the container to the bearing in a clean condition.

During storage, drums should be placed on their sides so that when there is "breathing", moisture will not be pulled into the drum. The ideal situation is to provide inside storage at constant temperature conditions. The lubricants should be stored so that the oldest drums are removed first, thus keeping a fresh stock.

It is good practice to transfer the lubricant directly from the storage drum to the reservoir or bearing without having the lubricant exposed to the atmosphere and subjected to possible contamination. With oils, the drums are moved from the lubrication rooms to the equipment on dollies and the oil pumped directly into the reservoir. Extra portable containers are not used except on isolated pieces of equipment. With grease, air operated pumps are used on the original drum which pump directly to the bearings. On some remote equipment, it is necessary to use a hand gun, and these are also pump-filled so that the grease does not come into contact with the air.

CENTRALIZED SYSTEMS

Wherever possible, it is advisable to avoid the hand method of lubrication and install mechanical lubricating devices on equipment. This removes the factor of human error which is still one of the big problems in any lubrication program. The installation cost of automatic lubricators may seem high, but it has been found that with this more positive method there will be longer equipment operating life and maintenance costs will be lower.

The Supervisor should be consulted by the Engineering Department on lubrication problems pertaining to the installation of new equipment. However, there are field installations which occur during construction which the Supervisor must watch to assure good lubrication. Grease lines, which are hand lubricated, should be extended so they are visible and easy to service. Where there are a number of lines, they should be brought out to a header set-up. Even with a conscientious lubrication group, if grease fittings are almost inaccessible, or close to fast moving parts, the chances are that they will not get the proper attention. Oil fill, drain lines, and sight glasses should be installed so they are accessible for checking and servicing. Inspection flanges should be provided on all gear and chain guards so that the bite of the gears or sprocket can be easily observed. By going to this additional expense during construction, many future man-hours will be saved, in addition to assuring more positive lubrication. These steps will also add to the safety of the men as it will keep them away from moving parts.

It should be the job of the Lubrication Supervisor on the initial servicing of new equipment to check the oil reservoir and interior of the machinery to see if the surfaces to be lubricated are free of all dirt and grit which might cause a premature gear or bearing failure. All new equipment should be adequately flushed on start-up and given a short break-in period.

The Lubrication Group is responsible for the installation and maintenance of all lubricating equipment and lines. All the men have been trained to make the repairs and installations. It has been found more satisfactory to have the Lubrication Group handle everything pertaining to the delivery of the lubricant to its point of usage.

The Lubrication Mechanics are responsible for cleaning up whatever lubricants are spilled while they are servicing the equipment, but do not have to clean up oil which leaks from poor seals or grease which is forced through mill sleeve bearings.

Lubrication will not be the scapegoat of mechanical failures when a practical appraisal of equipment requirements assures the use of proper lubricants and good supervision guarantees the supply. Sometimes it is difficult to place a dollar value on the increased productive time of equipment. However, there are tangible assets to a good lubrication program, such as reducing the total lubricant bill and lowering maintenance costs by reducing the frequency of breakdowns, which can be estimated in dollars. This will bring to management's attention the fact that a well-organized lubrication program is a paying proposition.

QUESTIONS AND ANSWERS

Q. As many as six types of lubricants may be used on a machine, based on a manufacturer's recommendations. Is this necessary?

A. In many cases, depending on the operating conditions, you cannot follow the manufacturer's recommendation 100 percent. We find that, due to temperatures which are over and above the rating of the manufacturer, overload conditions, or special operating conditions, we cannot follow the manufacturer's recommendations. Generally, we check with the manufacturer first. If he says that a lubricant cannot be used under the conditions specified we will make our own tests. Many of the large manufacturers are very conservative in their approach to lubrication. This is not a criticism, but I do believe it is up to the individual lubrication engineer to use his discretion. If something is not working properly, he should check with the manufacturer. When the manufacturer says no, their lubricant will not work, it is up to the lubrication engineer to go out and get something that will work.

Q. Why does your company perform such extensive tests on new lubricants? Doesn't the manufacturer make lubricant recommendations?

A. We are conservative insofar as changes are concerned and generally take as long to get rid of a lubricant as we do to put one in. For instance, when we changed to one multi-purpose grease it took us about a year and a half to be sure that it would do the required job in the plant. Oil companies have recommended lubricants which they said were equivalent, particularly EP lubricants, and we have found they were not equivalent and would not do the job. We have to protect our own position, too, and cannot take a blanket statement from an oil company representative. We realize that they are helping us, and that they are trying to present the most factual information they can, but, after all, we are assuming the responsibility for putting a lubricant into use, and it is the lubrication engineer's job to see that he has all the facts when he puts a new lubricant into service.

Q. If you hear a suspicious noise in a machine do you have any method of running it down to its source by the use of a rod or stethoscope or some other sound device to locate it more exactly?

A. We have used up to the present time a stethoscope. We now have a vibration analyzer on order that costs about $2000 and found it to be very satisfactory in locating the cause of the trouble.

Q. Do you schedule oil changes through the maintenance scheduling department? Who opens and cleans the large reservoirs?

A. We have a list, a schedule of all of the oil systems that have to be changed and the frequency with which they should be changed. A clerk in the maintenance office sends a slip to the lubrication supervisor when the oil should be changed, whether the oil is filtered and returned, whether the system is flushed, or dismantled and cleaned, and of course, the date. We thereby maintain a complete record of every system change. All of our changing is handled by the lubrication mechanics, cleaning and everything else.

Q. Does your company buy lubricants from one supplier or do you have several suppliers and buy competitively?

A. We have about five or six suppliers.

Q. In your paper you mentioned an oil temperature of 300 degrees Fahrenheit. Is that the oil temperature or to what does it refer?

A. The bearing temperature. The roll temperatures run about 300 degrees Fahrenheit, and we estimate the bearing temperature, with the coolant on the bearing box, may run 250 to 300 degrees Fahrenheit. The oil going through the bearing probably would hit that temperature, but is cooled when it returns to the reservoir.

CHARLES G. HOLLISTER

Mr. Charles Hollister graduated in 1935 with a degree in Mining Engineering from Lehigh University. After taking graduate work in Petroleum Engineering at the University of Texas, he worked as an engineer in the drilling and production departments of the Shell Oil Company and the Stanolind Oil and Gas Company in the Southwest. Later followed an assignment with the Kellex Corporation at Oak Ridge, Tenn. In 1945 he joined the Bakelite Company in Bound Brook, N. J., where he has been in the Maintenance and Plant Engineering Departments, now being the Department Head of the Plant Engineering Department. He is a member of the National Society of Professional Engineers, as well as the A.S.L.E.

Editor's Note: This completes the series of articles on the Plant Lubrication Program; however, the editors have recently received a new series of articles dealing with the training and organization of Plant Lubrication personnel. This material was presented before the recent Lubrication Engineering Course co-sponsored by the Kingsport Section and the University of Tennessee. Watch the Sight Glass for further announcement of this important series.

Laboratory Evaluation of the Resistance to Oxidation of "R & O" Industrial Oils

The following discussion shows that an unsuspected correlation exists between two dissimilar oxidation stability tests. It is not within the scope of this paper to endorse the use of any single test, nor is it intended that any reflection be cast upon the merits of oxidation tests which are not herein described. Also, it should be well understood that the oil characteristics measured by either or both of these tests are only part of the over-all picture. Many other vital qualities such as sludging tendency, rusting protection, emulsibility, and viscosity must be considered in relation to a given R&O oil application.

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As is characteristic of many aspects of lubrication, evaluation of the oxidation stability characteristics of lubricating oils is a controversial subject. This is reflected in the large number of different published procedures, of which those cited[1-8] are but a representative few. This situation is readily understandable in view of the complex composition of petroleum fluids and the variety of variables associated with the oxidation process.

Efforts to develop standardized oxidation procedures are usually viewed pessimistically on the basis that no two procedures have been known to correlate one with another. Also, it is often claimed that no laboratory rating procedure has been shown to correlate with field performance. The multiplicity of procedures, each with its group of proponents, has tended to retard progress in this field. Therefore, it is important to report any instance wherein one method has been found to correlate with another, especially when one of the methods is cheaper, less time-consuming, and easier to perform. It is the purpose of this paper to describe such a case.

While developing suitable laboratory methods for the selection and use of R&O circulating system oils, considerable oil oxidation data were obtained using two entirely different procedures. Those data show that either procedure will rate the forty oils which were tested in substantially the same relative order. One of the methods employed is considerably quicker and cheaper. The assumption that the ratings obtained with this method would be substantially the same as those which would have been obtained by the longer and more complicated method was later confirmed when an additional twenty-three individual proprietary products selected at random were evaluated by both methods.

W. C. Milz

E. M. Kipp

EXPERIMENTAL

A. Apparatus

1. Alcoa Oxygen Absorption Test

This test is based upon a modification of the procedure developed originally by the Continental Oil Company.[3]

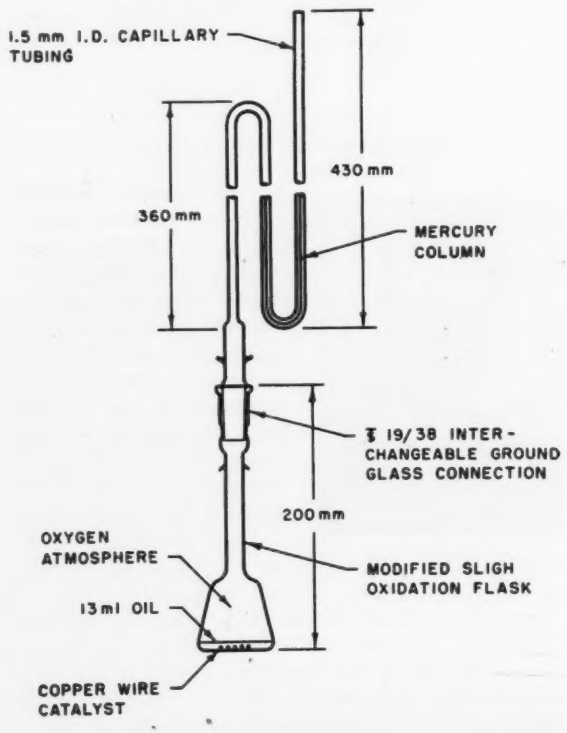

Figure 1. ALCOA oxygen absorption test.

Modifications include an increase in sample size from ten grams to thirteen milliliters, a change in catalyst from iron naphthenate to solid copper, and a reduction in testing temperature from 175° C. to 115° C. The details of the apparatus are shown in Figures 1 and 3. The essential components are a Sligh oxidation flask fitted with an integral ground glass connector to which the mercury filled open end manometer is attached. A catalyst in the form of five 2" lengths of 0.064" diameter copper wire is used.

2. ASTM D-943 Turbine Oil Stability Test[8]

The essential features of this apparatus are shown in Figures 2 and 3. Briefly, it consists of a large glass test tube, a glass mushroom type water condenser, and an oxygen gassing tube which also supports the catalyst. The catalyst is a composite coil of copper and iron consisting of three meter lengths of #14 A.W.G. iron wire and 0.064" diameter electrolytic copper wire.

3. General Auxiliary Apparatus

The desired oil oxidation temperatures were obtained with constant temperature oil baths, each of which was capable of maintaining the oil temperatures within a maximum range of ± 0.5° C.

A Cenco DuNuoy Tensiometer, Model 70532, was used for determination of interfacial tension values of the samples of oil undergoing oxidation.

The neutralization values of the oil samples were determined with a Beckman glass electrode pH meter, Model No. H-2.

The viscosity values were determined with calibrated Ostwald-Fenske viscometers.

B. Test Oils

Forty rust and oxidation inhibited (R&O) oils were obtained for this work. Selected from the products of fourteen oil companies, a wide range of viscosities and inhibitor types are represented. A few of the chemical and physical characteristics of the oils are listed in Table II, where it will be noted that the different inhibitor types are often reflected in unusually low interfacial tension values or high neutralization values, or both.

C. Procedure

1. Alcoa Oxygen Absorption Test

The Sligh oxidation flask was thoroughly cleansed and dried. Thirteen milliliters of oil were pipetted into the flask, care being taken to avoid splashing of the oil sample or contact of the oil with the sides of the flask. The sec-

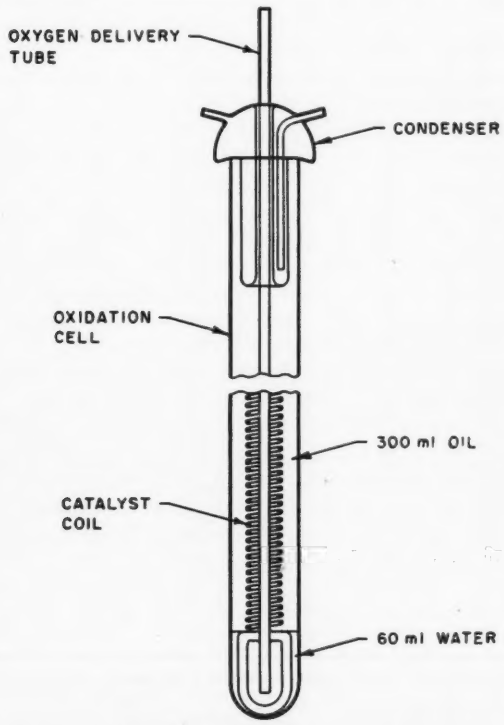

Figure 2. ASTM D-943 turbine oil stability test.

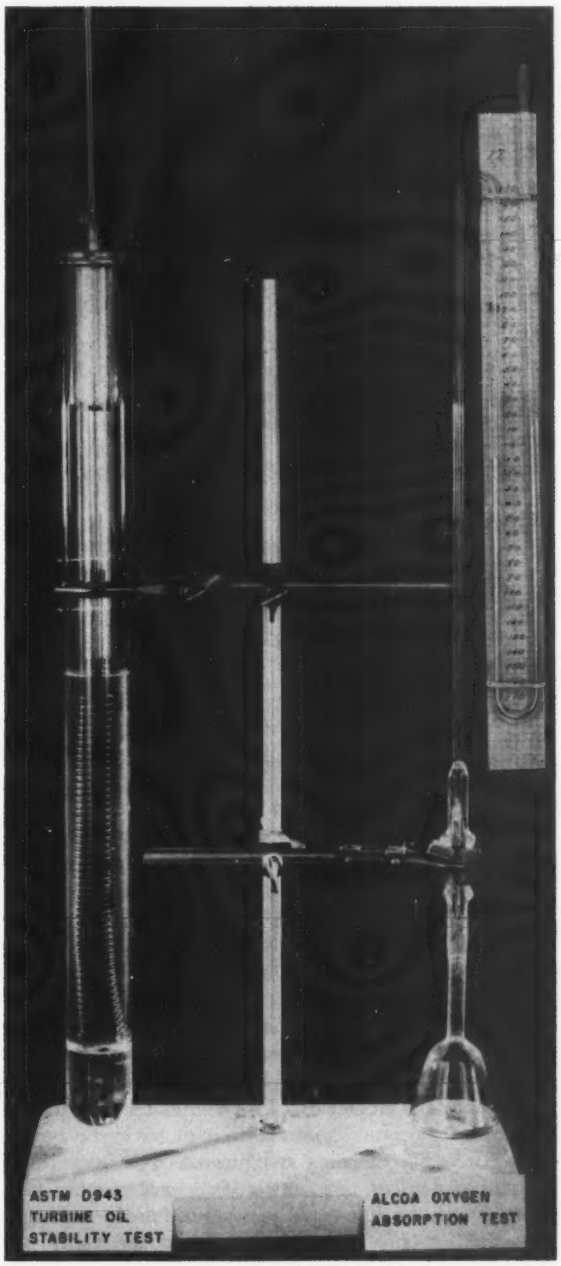

Figure 3.

Table I

Oxidation Stability Characteristics of Forty Representative R&O Type Oils

Oil Code Number	Alcoa Oxygen Absorption Test at 115°C. (Hours)	ASTM D-943 Turbine Oil Stability Test (Hours)
H1	370	1250
B1	345	950
G3	305	1160
L2	281	1090
L3	253	2170
H4	224	840
K1	204	720
N1	151	580
K2	131	480
G2	118	650
K3	106	410
A1	85	540
E3	85	980
H2	84	1740
E2	81	670
D1	78	510
E4	75	810
F1	73	450
E5	66	1190
A3	62	420
F2	57	420
H3	54	240
A2	52	390
L4	50	320
G4	44	240
P1	40	270
E1	38	230
F3	35	240
F4	34	190
L1	32	170
J3	32	160
E6	30	210
M1	29	190
G1	27	230
C1	27	120
D2	22	90
P2	18	80
J2	16	380
F5	15	50
J1	14	50

tions of copper wire catalyst were added and the flask thoroughly purged with tank oxygen. The open end manometer was then attached to the flask and the assembly placed in the thermostatically controlled oil bath. The flask was immersed to within approximately 1½ inches of the ground glass joint. The temperature of the oil for the work reported in this paper for all the oxidation tests was held at 115° C.

After immersion of the apparatus in the oil bath, the manometer readings rise rapidly because of expansion of the oxygen gas and the increased vapor pressure of the oil at the oxidation temperature. Fifteen minutes were allowed for major temperature and pressure changes in the apparatus. After this, the time and pressure were recorded as the start of the test. Manometer readings were taken periodically until the differential pressure had dropped 60 mm. from the highest pressure attained during the test.† The elapsed time, in hours, was recorded as the oxidation period. It was assumed that the longer the oxidation period, the better the stability characteristics of the oil.

2. ASTM D-943 Turbine Oil Stability Test

All glass parts of the apparatus were thoroughly cleansed and carefully dried. The composite catalyst coil was slipped over the inlet of the gassing rod, and the assembly inserted in the cell. After pouring a 300 ml. portion of the test oil over the catalyst coil, the cell was partially submerged in a constant temperature oil bath set at a temperature high enough to maintain the oil within the cell at 95° C. The water condenser was positioned and the gassing rod connected, via a flowmeter, to an oxygen supply. The oxygen flow rate was adjusted to approximately three liters per hour. Thirty minutes after the start of the test, 60 mls. of distilled water were added

Table II

Physical and Chemical Characteristics of the R&O Type Oils Tested

Oil Code Number*	Neut. Value	IFT Value	Viscosity SSU/100°F.	Vis. Index	Specific Gravity 60°/60°F.
A1	.12	40.6	321	112	.871
A2	.08	38.6	307	110	.875
A3	.12	46.0	2200	103	.895
B1	.11	18.2	154	107	.867
C1	.04	31.1	281	72	.901
D1	.09	28.8	915	94	.888
D2	.04	38.8	2510	102	.898
E1	.11	35.2	303	67	.894
F1	.04	23.2	310	102	.880
F2	.09	23.0	610	94	.887
F3	.16	15.0	610	98	.887
F4	.16	22.2	956	97	.892
G1	.04	18.6	536	102	.885
F5	.12	25.2	2450	97	.902
H1	.08	17.1	108	110	.856
H2	.04	19.7	200	93	.870
H3	.20	22.2	304	86	.881
H4	.04	22.1	739	99	.879
J1	.08	37.2	154	102	.868
J2	.21	37.6	304	100	.880
J3	.29	36.6	1270	94	.896
K1	.08	16.8	145	92	.873
K2	.08	16.9	280	90	.879
K3	.08	19.1	446	85	.884
L1	.12	20.6	106	0	.904
L2	.04	28.5	144	91	.874
L3	.45	9.3	309	34	.897
L4	.08	28.5	966	95	.882
M1	.09	23.5	429	86	.885
E2	.12	36.0	104	115	.855
N1	.09	18.0	109	83	.866
G2	.08	16.4	122	110	.870
G3	.08	16.4	161	108	.869
G4	.08	—	1930	93	.894
E3	.16	36.6	153	112	.863
E4	.05	41.5	315	107	.871
P1	.13	33.5	375	113	.880
P2	.08	30.9	329	30	.931
E5	.08	36.6	314	110	.870
E6	.08	31.2	306	45	.908

*Each different prefix letter represents a different supplier.

†The highest pressure often occurred several minutes to several hours after the start of the test.

to the contents of the cell. Samples of the oil under test were taken periodically and the neutralization numbers and interfacial tensions determined. A test run was considered to be complete when the neutralization number attained a value of 0.4 or when the interfacial tension value had dropped to 18.* The selection of these values as end points for the test was based upon prior extensive experience with the use of this procedure. It had been noted consistently that whenever one of these limiting values was attained, there were always definite indications that the oil was, or would soon be, deteriorated to an undesirable extent as indicated by deposition of sludge on the catalyst coils or in the reaction cell, or by the characteristic "burnt" odor of the oil. For these reasons, the selected end points are not considered to be arbitrary.

TEST DATA

The oxidation stability characteristics of the forty commercial R&O oils upon which this investigation was based, as determined by both the Alcoa and the ASTM procedures, are presented in Table I.

The correlation coefficient "r" for the two sets of data in Table I was computed using a simple linear regression and correlation. The calculated value thus obtained was 0.698, indicating a significant correlation. This was further confirmed by calculations indicating that for a value of "r" of 0.698 and on the basis of the 40 samples involved, the correlation value is significant at the 99% level of confidence.

As a matter of interest, it was noted in comparing the ASTM data with the Alcoa data that four of the forty ASTM data were very far out of line, using the Alcoa data as a reference. Elimination of the data for these four oils increased the correlation coefficient "r" to 0.882. It is evident, therefore, that the four oils had a disproportionately adverse effect on the correlation factor.

There is a tendency to overlook the fact that oxidation stability measurements, in common with many other measurements in the field of lubrication, are not basically of a precise nature. Reproducibility of ± 10-20% in oxidation stability measurements would normally be considered good and, in fact, is often the best that can be obtained. It is evident, therefore, that calculation of a correlation factor as indicated using the specific number of "hours" of oxidation stability is an unduly severe standard for the degree of experimental precision involved.

In the great majority of cases, from a practical point of view, the number and variations of operating conditions are such that it is often sufficient to know merely whether one oil is appreciably superior to another. Accordingly, the correlation coefficient between the ASTM and the Alcoa procedures was recalculated. This was done on the basis of unit ratings, whereby the oil having the longest run by the Alcoa procedure was rated #1, the second longest #2, etc. An identical procedure was followed in rating the oils by the ASTM procedure. The correlation coefficient between these two ratings on this basis was 0.895, representing a highly significant value. It would have been even more so had the ratings been grouped in levels of outstanding, good, fair, and poor—ratings which would be more than adequate for many field applications.

APPLICATION OF TEST DATA

On the basis of the significant correlation which was found to exist between the ASTM D-943 Turbine Oil Oxidation Test and the Alcoa Oxygen Absorption Test, consideration was given to the feasibility of utilizing either test in the screening of oils. While there is no general agreement as to the number of hours by the ASTM test which would represent a satisfactorily stable R&O oil, discussions of this subject with other workers in this field have revealed a preference for a minimum of 500 hours. If a figure of 75 hours is selected as a minimum requirement for the Alcoa oxidation test, it will be noted in Table I that only two of the oils meeting that requirement did not meet a minimum run of 500 hours on the ASTM test. Also, of the 40 oils which were tested by both procedures, 22 would have been rejected by a minimum requirement of 75 hours with the Alcoa oxidation test. Of this group, all but one would also have been rejected on the basis of a 500-hour minimum test run requirement on the ASTM test.

It is evident, therefore, that a minimum 75-hour Alcoa oxidation requirement would achieve essentially the same selection as would have been established had the products been screened with a minimum requirement of 500 hours by the ASTM procedure.

Subsequent to this decision, an entirely new group of 23 proprietary turbine oils was screened by the modified Alcoa test and also by the ASTM test with minimum oxidation run requirements of 75 and 500 hours, respectively. There was agreement on 22 of the products, both methods rating the same fourteen oils satisfactory and eight oils unsatisfactory. The one remaining oil failed to meet the Alcoa 75-hour minimum requirement but did exceed the ASTM 500-hour minimum value.

REPEATABILITY OF ALCOA TEST

Finally, before accepting any alternative test procedure, it is always worthwhile to make certain that satisfactory precision or repeatability may be expected from the new test, although it is well realized that any calculation of precision is subject to certain limitations. In the present instance, for example, two of the limitations are that only two results were obtained on each oil, and that all tests were conducted in essentially the same apparatus. However, it is believed that these shortcomings were offset to some extent by using two different operators to perform the tests, and by including forty different oils.

Each Alcoa test result reported in Table I is an average of two test results. To arrive at the precision of the method, standard deviations were calculated. Each standard deviation was then divided by the arithmetical average and multiplied by 100 to arrive at a percentage measurement of precision. These measurements varied from a minimum of 0% to a maximum of ± 18%, with an over-all average of ± 6%. Best precision was obtained in the runs of average length. In fact, if only those data nearest to the 75-hour requirement are considered — for example, the

*An R&O type oil may contain an additive or additives which lower the interfacial tension, sometimes to the extent that the interfacial tension of the new oil is below 18.0. Under oxidation conditions the interfacial tension of such an oil will rise to some value above 18.0 owing to depletion of the additive; then, when the additive is nearly or completely consumed, the interfacial tension will drop in the usual manner because of increased accumulation of oxidation products.

twelve results in the 51-100-hour range—it was found that, on an average basis, a replicate result fell within ± 4% of its duplicate result.

CONCLUSIONS

1. A significant degree of correlation in the oxidation stability rating of R&O oils has been found to exist between the Alcoa Oxygen Absorption Test and the ASTM D-943 Turbine Oil Stability Test.

2. Screening of oils on the basis of oxidation stability by the Alcoa test procedure based upon a minimum requirement of 75 hours will result in substantially the same ratings as would be obtained utilizing the ASTM D-943 turbine oil procedure with a minimum requirement of 500 hours.

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ACKNOWLEDGEMENT. The writers wish to acknowledge the assistance of F. R. Austin and W. M. McClintock in performing most of the test work covered in this paper.

Book Reviews

"ASTM Manual for Rating Motor Fuels by Motor & Research Methods;" American Society for Testing Matrials, 1916 Race St., Philadelphia 3, Pa., 1956; 192 pages, cloth binding, price $6.75.

Careful study and use of the "ASTM Manual for Rating Motor Fuels by Motor & Research Methods" should enable qualified personnel to install and operate knock testing equipment for both the motor and research methods. This manual was prepared by ASTM Committee D-2 on Petroleum Products & Lubricants (1) to revise and bring up to date the ASTM methods for determining the knock characteristics of motor fuels by the research and motor methods, and (2) to better serve users of ASTM knock test engines by providing six appendices presenting by word and picture, factual information and data on the operation and maintenance of the knock testing equipment.

Methods are: Standard Method of Test for Knock Characteristics of Motor Fuels, by the Motor Method (D-357); and Standard Method of Test for Knock Characteristics of Motor Fuels, by the Research Method (D-908); commonly referred to as the Motor and Research methods. Also included are six appendices (I-Apparatus; II-Reference Materials & Blending Accessories; III-Operation; IV-Maintenance; V-Installation & Assembly; VI-Building & Utility Requirements) containing valuable and necessary information for conducting standardized octane ratings on motor fuels. Short statements on the essential features of each method are included. The manual is illustrated throughout. In addition to drawings and photographs there are numerous tables and charts and a complete index.

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The Equilibrium Distribution of Transfer Fragments

During sliding, fragments are continually torn off one surface and transferred to the other. The final stages of this process are examined; and it is shown that two possible states of equilibrium exist, depending on the tightness of bonding of the transferred fragments. If the fragments are fairly loose, each surface normally retains its original configuration to a large extent; but if the fragments are tightly held, one surface often becomes completely covered by fragments of the other. A variety of experimental data is examined, and good agreement with the derived equations is found.

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When two surfaces are slid together, fragments are continually torn off one and transferred to the other. A large number of measurements of the initial stage of this transfer process have been carried out, but there have been few investigations, either theoretical or experimental, in which the later stages of the process have been examined. This is surprising, indeed, when it is realised that continuous sliding of surfaces over each other is the rule rather than the exception. In this paper we propose, after making simplifying assumptions, to calculate first the equilibrium configuration and second the rate at which it is attained, and to compare the calculations with experimental findings.

Arguing intuitively we might imagine that, after sliding had continued for a very long time, the two materials had become thoroughly intermingled, so that the surface of each specimen consisted of the same proportion of the two constituents. Experimental tests suggest, however, that this does not often occur when sliding takes place in air, though the phenomenon is occasionally observed. Instead, it is usually found that each surface still consists largely of its own bulk material, but with a small fraction covered by fragments from the other surface.

CALCULATION OF THE EQUILIBRIUM

The choice between the two possible terminal states is determined by the tightness with which the transferred fragments are held on the other surface, and two separate calculations are necessary to cover the two situations.

Case A, Fragments Held Loosely

We shall assume that a rider of copper is sliding on a steel surface, that a fraction (a_1) of the copper and (a_2) of the steel surface are covered by fragments of the other metal, and that all the fragments, both of copper and of steel, are of the same size and shape (Figure 1). Further, we define p as the probability per contact of transfer from copper to copper, q as the probability per contact of transfer from steel to steel, r as the probability per contact of transfer from copper to steel, and s as the probability per contact of transfer from steel to copper.

The rate at which copper fragments arrive at surface II is equal to the total number (N) of junctions formed, multiplied by the fraction of surface I that is copper ($1-a_1$), the fraction of surface II that is steel ($1-a_2$), and the probability that a contact will produce a fragment (r). Similarly, the rate at which copper fragments leave the surface equals N multiplied by the concentration of copper in the bottom surface (a_2), the concentration of copper in the top surface ($1-a_1$) and the appropriate probability factor (p). Hence, for equilibrium we write

$$N(1-a_1)(1-a_2)r = N(a_2)(1-a_1)p \tag{1}$$

and hence

$$a_2 = r/(p+r) \tag{2}$$

Similarly, by examining the flux of steel fragments in surface I, we get

$$a_1 = s/(q+s) \tag{3}$$

It should be noted that, in deriving these equations, we have assumed that transferred fragments are not held too tightly to the other metal and are unable themselves to pull out any further fragments. The case where fragments induce the formation of more fragments is discussed later.

In calculating the constants p to s we must use transfer data obtained over small sliding distances, before the contamination of either surface by fragments from the other has become severe. For copper on steel, the constants as given by Archard[1] are $p = 320$, $q = 450$, $r = 15$ and $s = 5$, all in units of 10^{-4}. Hence, we calculate the values for a_2 and a_1 as 4.5 and 1.1% respectively. Although the approximations in the calculations have been severe, it is believed that the values of a_1 and a_2 are correct, at least to within one order of magnitude.

According to equations (2) and (3), the equilibrium configuration depends only on the wear constants p to s, and, in so far as these are almost independent of load, speed and surface geometry, so is the equilibrium. Some experiments by Kerridge[2] sliding a soft steel rider on a hard steel cylinder confirm in a striking way the fact that a_1 does not depend on the applied

E. Rabinowicz

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load. When the load was changed by a factor of 10, the weight of fragments adhering in equilibrium to the cylinder changed by less than a factor of 30%. His data also provide a direct test of equation (3). The area of his sliding surface was 4 cm^2; the volume of transfer was 10^{-4}cc. Assuming the diameter of a fragment to be 10^{-3} cm, a reasonable value; this gives $a_1 = 2.5\%$. From his graphs we can estimate an initial transfer rate and calculate s as being 5×10^{-4}. As above, q may be taken to be 450×10^{-4}. Thus, from equation (3) we find $a_1 = 1.1\%$. In view of all the uncertainties, this seems as close to the actual value of 2.5% as we could reasonably expect.

Of some interest is the system titanium against steel. Values of the coefficients, $p = 220$, $q = 450$, $r = 90$ and $s = 20$ (all $\times 10^{-4}$) are derived, as incidentally were Archard's values, from our own experimental data. Thus we find concentration of steel on titanium surface = 4.3%; concentration of titanium on steel surface = 29.0%.

In an earlier paper[3] we postulated that, whenever more than 10% of a metal surface was covered by fragments of the other metal, these latter would be so close together that although each separately was too loosely held to pull off a fragment, together they could co-operate in pulling fragments from the other surface. In consequence, the equilibrium configuration could have much more than 29% of the steel surface consisting of titanium fragments. This deduction is indeed borne out by experiment.[4] When titanium and steel are slid together, the steel surface is rapidly covered by titanium fragments and the sliding behavior becomes the same as if titanium had been slid on titanium.

Table I shows calculation of (a) for the above combinations of materials and the others given by Archard. None of the values for (a), other than that for titanium on steel, is as high as 10%, and none of the other surfaces is normally covered by fragments during sliding.

The most extensive experimental work appears to be that of Sakman, Burwell and Irvine[5] who slid various small metal riders on a radioactive copper-beryllium alloy, and measured the transfer of activity to the riders. The fragments on the riders seem to have achieved equilibrium, as calculations suggest and the data show. Table II is derived from the experimental values presented in Table VII of their paper.

The results are of the same order of magnitude as those shown in Table I, and the two materials giving high fragment concentration (above 10%) are those we would expect to form strong welds with copper-beryllium, namely copper beryllium itself and phosphor bronze.

Case B, Fragments Held Tightly

Referring to Figure 1: if the copper fragments on surface II can pull further copper fragments to surface II, we must add a term $N(a_2)(1 - a_1)p$ to the left-hand side of equation (1). If the steel fragments on surface I can pull copper fragments off surface II, we add a term $N(a_2)(a_1)r$ to the right-hand side. Thus we obtain

$$N(1 - a_1)(1 - a_2)r + N(a_2)(1 - a_1)p = N(a_2)(1 - a_1)p + N(a_1)(a_2)r \quad (4)$$

or

$$a_1 + a_2 = 1 \quad (5)$$

Clearly the same relation between a_1 and a_2 will be obtained by considering the steel fragments and, hence a_1 and a_2 cannot be determined separately. However, it is clear that at least one of them must be ½ or above. In practice, one of them is usually 1 and the other zero, the choice being determined partly by chance and partly by surface geometry. As a later calculation shows, when we slide a small rider on a large flat surface, the initial concentration of fragments will normally be larger on the rider, so this is more likely to be the surface that is completely covered by fragments of the other. A number of such cases are reported in the literature, e.g. platinum on silver, and copper on silver.[6] In all such cases the metals are chemically similar, and tightly adherent fragments are to be expected. The case of titanium on steel discussed earlier may also belong to this category, but it is likely that the large concentration of titanium fragments, as well as their tight bonding, contributes to the 100% coverage.

The case of transfer between specimens of the same size, shape, and material is discussed by Feng[7] who finds, using the argument of symmetry, that $a_1 = a_2 = ½$. Equation (2) shows that this is correct for case A since we have $p = q = r = s$, but equation (5) shows that it is only one correct equation out of many for case B. If we draw a plane at the surface of one of the specimens (Fig-

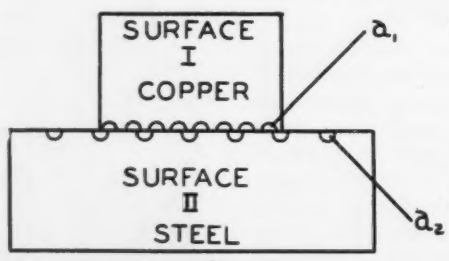

Figure 1.

Table I

Equilibrium Concentration of Transfer Fragments For Various Metal Combinations

Fragments	Surface	Equilibrium Concentration, %
Platinum	Silver	.3
Cadmium	Steel	.6
Steel	Copper	1.1
Platinum	Steel	3.7
Steel	Titanium	4.3
Copper	Steel	4.5
Titanium	Steel	29.0

Table II

Measured Equilibrium Concentrations* Copper-Beryllium Fragments

Surface	Concentration	Surface	Concentration
Chromium	.6%	Silver	4.4%
Lead	.8	Nickel	5.1
Tin	.9	Tin	7.6
Aluminum	2.0	Copper-Beryllium	48
Cadmium	2.9	Phosphor Bronze	103
Zinc	4.3		

*Data derived from work of Sakman, Burwell and Irvine.[5]

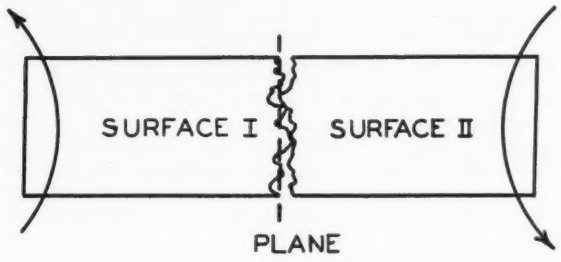

Figure 2.

ure 2) such that the volume of specimen I to the left of the plane is the same as the volume of specimen I terminated by its actual surface, then each time a fragment is transferred to surface I the plane moves a small distance to the right; each time a fragment is transferred to surface II, the plane moves correspondingly to the left. Wear being a random phenomenon, the position of the plane varies in a random fashion. The problem of finding the position of the plane under these random disturbances is the same as that discussed by Einstein[8] for the Brownian movement of particles; and the result is that, in general, the plane is distant from its starting position by an amount which varies as $(\text{time})^{\frac{1}{2}}$. Thus, after a long period of sliding, it is more probable than not that the line of demarcation will have moved into one of the specimens, so that one out of a_1 and a_2 is zero and the other is 1.

These considerations apply also when the specimens are not symmetrical. Figure 3 shows that when we slide a radioactive copper rider on a flat surface, the metal transfer to the flat surface is spasmodic. The autoradiograph consists of a series of black lines, corresponding to regions where the transfer is into the bottom plate, and blank regions when the top rider is covered by fragments of the bottom surface ($a = 1$) and no transfer is observed. These correspond to the excursion of the plane into the rider and the flat surface respectively.

Rate of Transfer as a Function of Sliding Distance

For the system whose equilibrium is given in equation (1), we can write the rate at which equilibrium is attained in the form

$$\frac{d(a_2)}{dn} = \frac{A_F}{A_T} \times \left\{ N(1-a_1)(1-a_2)r - N(a_2)(1-a_1)p \right\} \quad (6)$$

where n is the number of passes over the same track (or, for a rider, the number of times the rider moves a distance equal to its length, A_F the area per fragment and A_T the total, or design, area of contact. It is assumed that the surfaces will run in until all parts of the surface that could make real contact will have done so. The term in the bracket is the difference between the left-hand side and right-hand side of equation (1).

Rearranging the terms and putting $K = A_F N/A_T$, we get

$$\frac{d(a_2)}{dn} = K(1-a_1)\left\{ r - a_2\,(r+p) \right\} \quad (7)$$

We can solve this equation most simply by ignoring the factor $(1-a_1)$ since a_1 is usually small. Then we integrate to obtain

$$a_2 = \frac{r}{r+p}\left\{ 1 - e^{-(r+p)nK} \right\} \quad (8)$$

Feng has intuitively derived an equivalent exponential expression for the symmetrical case. The experimental data of Kerridge show that the rate of increase of a with time is indeed more or less exponential, but he finds that his curve has a more pronounced tail than the exponential one. Part of this, no doubt, arises from the omitted term $(1-a_1)$ in equation (7) which will tend to reduce the rate of transfer when equilibrium is nearly attained. However, the main reason for the tail is doubtless that given by Kerridge, namely that the fragments are located at different levels on the surface, and that it takes longer to place, or replace, a fragment in a dip or hollow.

Equation (6) shows that da/dn is inversely proportional to the sliding area A_T. If we slide a small rider on a large surface, the rider will reach equilibrium first. Thus, if there is a tendency for one of the surfaces to be covered by fragments of the other, it will be a rider. On the other hand, if no such tendency exists, the rider will lose more weight in establishing equilibrium on the flat than it gains from the flat, so that a net loss in weight will be observed. These deductions both accord well with experience but are difficult to explain on empirical grounds.

DISCUSSION

The mathematical solution for the distribution of transfer fragments has been based on a simplified model, and the fact that the real sliding system is more complicated means that numerical correction factors might be introduced to advantage. The variation in size of the actual transfer fragments produces no complications, for Archard has shown that the same values of the probability coefficients p to s are obtained independent of the assumed size distribution, but a variation in shape would introduce the need for a correction factor. A more serious source of error is the assumption that the fragments either produce no further fragments or their full quota, and in practice some intermediate efficiency seems more probable. No experimental data are available on this point.

The occurrence of loose wear fragments is of interest

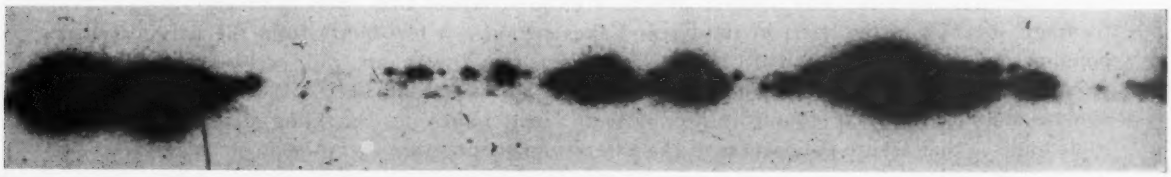

Figure 3. Autoradiograph produced after sliding radioactive copper rider on copper surface. Note the spasmodic nature of the wear.

and of practical importance These will serve in case B, to prevent the line of demarcation between the specimens from wandering too far from its original position. Unless the rate of formation of loose fragments is great (in some simple experiments we have found this rate to be about ¼ the transfer rate), no correction to the expressions for a_1 and a_2 seems necessary.

We must also consider the effect of introducing a lubricant. Experiments suggest that boundary lubricants reduce p to s in approximately the same proportions[9] so that the values for a_1 and a_2 will remain the same. However, in many cases the use of a lubricant will change the tightness of the bonding of fragments from case B to case A, and thus change the whole transfer pattern. Changes of atmosphere—in particular, use of a vacuum with outgassed specimens—may have an opposite effect and may convert the transfer pattern from case A to case B.

The wear process is known to be very complicated, and this makes the derivation of wear properties from the basic surface and bulk properties of the sliding materials very difficult and uncertain. Considering an analogy with plasticity, the derivation of the laws of plasticity starting with dislocations is very complex; however, once assuming these laws, the calculation of plastic flow for any simple system is much easier. In the wear case, also, we feel that once assuming the Archard wear constants, the calculated equilibria should be reliable at any rate to within an order of magnitude.

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COMMENTARY

C. GOODZEIT, GENERAL MOTORS RESEARCH STAFF

Mechanical wear is such a complex problem that it is approached from many aspects. Perhaps the most fundamental way to gain information on wear is to study the wear particles themselves. The nature of the detachment and transfer of fragments between sliding metal surfaces is therefore basic to the problem

This paper discusses the equilibrium distribution of transferred metal fragments on the surface of sliding metals. It seems reasonable to expect that under given conditions of speed, load and geometry, an equilibrium would be reached in the wear process in which a certain portion of the surface areas of the two metals are covered with fragments of the other metal. That this equilibrium is independent of speed, load, and geometry, however, appears doubtful. These doubts are founded in the formulation of the equations of the equilibrium conditions in the test of the paper.

In the development of the equilibrium equations, it is assumed that the transfer of metal takes place with equal probability from the asperities of the base metal and also from the fragments of the other metal that are attached to the asperities of the base metal. This assumption is not stated, yet it is basic to the derivation of the equations. Moreover, for a pair of sliding metals, the highest asperities of the surface received the transferred fragments. These fragments are, therefore, most likely to be transferred back to their original metal surface. Consequently, the portion of the base metal surface that is covered with fragments of the other metal is more likely to yield fragments than the base metal itself. Thus, a weight factor should be applied to the equilibrium equations to account for this condition. Furthermore, this weight factor would be related to speed, load, and geometry, factors which affect the degree of contact between the surface asperities of the sliding metals.

AUTHOR'S CLOSURE

I am in entire agreement with Dr. Goodzeit that speed, load, and geometry will affect the equilibrium distribution of the fragments. However, I feel that in most cases these changes will not be too great and will, in fact, represent second order effects. Although weight factors might be introduced to allow for these variations, the experimental data available is far too sparse to make this profitable at present.

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Patent Abstracts

(Compiled by Ann Burchick, Aluminum Co. of America.)

Extreme Pressure Lubricant, Patent No. 2,726,209 (M. Fainman, assignor to Standard Oil Co.) A composition suitable for use as a lubricating oil for the lubrication of metal to metal contact surfaces under conditions of extreme pressure between said contact surfaces, which composition is obtained by heating at a temperature of 225 F. to 275 F. for at least 10 hours and not more than 120 hours, a mixture consisting essentially of 5 to 10 parts by weight of sulfur-containing lead tallate slurried in 5 to 10 parts by weight of a lubricating oil diluent having a viscosity within the range of about 40 to about 200 at 210 F. (SSU), 1 to 10 parts by weight of a chlorinated paraffin wax of chlorine content within the range of about 40 to about 70% by weight of chlorine and from about 2 to about 6 parts by weight of oleic acid and adding sufficient lubricating oil having a viscosity of about 40 to about 200 seconds at 210 F. (SSU) to provide a total of 100 parts by weight of said lubricating oil composition which sulfur-containing lead tallate is produced by sulfurizing tall oil with free sulfur to obtain a sulfur-containing tall oil product containing 5 to 15% by weight of sulfur and non-corrosive to copper and heating at a temperature of about 220 F. to about 230 F., a slurry of said sulfur-containing tall oil in said lubricating oil diluent in the presence of about 20% by weight, based on the weight of said sulfur-containing tall oil, of an oxide of lead suspended in said lubricating oil diluent.

Lubricants, Patent No. 2,726,210 (M. L. Sharrah, assignor to Continental Oil Co.) As a new composition of matter the compound obtained by reacting a mixture comprising an olefin-nitrosyl halide adduct, a water soluble alkali metal sulfide, alcohol, and water at a temperature of from 20 to 100 C. and for a period varying from ½ to 5 hours, then allowing the product to separate into two layers an upper organic layer and a lower aqueous layer, and then recovering and drying said organic layer to obtain the said new composition of matter.

Pour-Point Depressor, Patent No. 2,726,212 (A. W. Weitkamp & W. S. Higley, assignors to Standard Oil Co.) A method for preparing a low pour-point stock solution of a pour-point depressor obtained by reacting a chlorinated wax with an aromatic hydrocarbon in the presence of a Friedel-Crafts catalyst, which comprises diluting said pour-point depressor with a lube-oil base, contacting the resulting solution with between about 1 and 70 percent by weight of urea, based on said pour-point depressor, and a urea solvent and separating the solids from the resulting reaction mixture, whereby a stock-solution of said pour-point depressor is obtained having a lower pour-point and improved effectiveness as a pour-point depressor.

Liquids Having Improved Temperature-Viscosity Relationship, Patent No. 2,726,213 (Ettore da Fano, assignor to John B. Pierce Foundation). A liquid characterized by properties rendering it stable for use as the power transmitting means in a hydraulic system, including good chemical stability, which is non-gumming, nonsludging, nontoxic and noncorrosive, and which has a relatively flat temperature-viscosity curve, consisting essentially of about 83% by weight of cresyl-triisopropyl orthosilicate and about 17% by weight of a 55% solution of polymerized methyl ester of acrylic acid in 200 F. minimum flash oil, said solution having a flash point of 215 F. and a fire point of 225 F. when diluted to 30% solids with base oil, and said solution having a viscosity of 55 cs. at 210 F. and neutralization number of 0.3.

Non-Foaming Drilling Fluid, Patent No. 2,727,002 (D. A. Rowe, assignor to Sun Oil Co.) A drilling fluid comprising salt water containing at least 150,000 p.p.m. of salt and having dispersed therein a material selected from the group consisting of colloidal clay and oil, and a minor amount of Turkey-red oil sufficient to inhibit foaming.

Marine Engine Oil Containing a Petroleum Oxidate, Patent No. 2,727,005 (J. K. McKinley, M. R. Hefty & A. J. Deutser, assignors to The Texas Co.) A lubricating composition adapted to form emulsions of the water in oil type in the presence of water, consisting essentially of a mineral lubricating oil of predominantly naphthenic character having a Saybolt Universal viscosity at 100 F. in the range from about 400 to 1500 seconds, and about 1-10 per cent by weight of a petroleum oxidate characterized by a maximum neutralization number of about 35, a saponification number of about 90-145, a ratio of neutralization number to saponification number below about 0.25 and a Saybolt Universal viscosity at 210 F. above about 1500 seconds.

Textile Lubricants, Patent No. 2,727,860 (M. Duke, F. Fortess & C. Hohing, Jr., assignors to Celanese Corp. of America). A textile lubricant comprising from about 30 to 65% by weight of a mineral oil, from about 2 to 5% of an alkyl phenol, from about 2 to 6% by weight of a substance selected from the group consisting of the formyl, acetyl, propionyl and butyryl esters of castor oil, and butyl acetyl ricinoleate, of from about 5 to 25% by weight of a substance selected from the group consisting of oxidized peanut oil, sulfonated olive oil, sulfated higher fatty alcohols, oxidized olive oil and oxidized teaseed oil, from about 2 to 10% by weight of a higher fatty acid, from about 3 to 20% by weight of an amine, and from about 4 to 20% by weight of an alkyl phosphate.

Hydrocarbon Oils, Patent No. 2,727,006 (J. Dazzi & J. E. Fields, assignors to Monsanto Chemical Co.) A substantially foam-resisting hydrocarbon oil composition containing up to 1.0 per cent by weight, based on the weight of the composition, of homo polymeric di-n-butyl itaconate.

Mineral Oil Compositions Containing Polymers of Alkyl n-Substituted Maleimides, Patent No. 2,727,862 (J. J. Giammaria, assignor to Socony Mobil Oil Co., Inc.) A mineral lubricating oil containing a small amount, sufficient to improve the viscosity index thereof, of a polymerized n-alkyl maleimide, the alkyl substituent of said maleimide having from about 8 to about 18 carbon atoms.

Anti-Corrosion Turbine Oil, Patent No. 2,728,728 (S. C. Vaughn, assignor to Tide Water Associated Oil Co.) A hydrocarbon lubricating oil containing in solution as an essential rust-inhibiting component the product resulting from the admixing of at least 0.005% by weight of alkyl acid phosphate having from 8 to 16 carbon atoms per alkyl group and furfuryl amine in quantity from 50% to 150% of the amount theoretically required to neutralize the alkyl acid phosphate.

Textile Lubricants, Patent No. 2,730,498 (Fred Fortess & C. Hohing, Jr., assignors to Celanese Corp. of America) A textile lubricant comprising an aqueous emulsion containing 400 parts by weight of water and a lubricant composition containing (A) 15 parts by weight of the partial ester of phosphoric acid with decyl alcohol, (B) 20 parts by weight of the condensation product of triethanolamine and cocoanut oil fatty acids, (C) 3.5 parts by weight of triethanolamine, (D) 2.5 parts by weight of diamyl phenol, (E) 39 parts by weight of mineral oil, and (F) 20 parts by weight of the polyethylene oxide ester of lauric acid.

Lubricants for Heavy Journal Bearings Operating at Elevated Temperatures, Patent No. 2,730,499 (O. S. Pokorny, assignor to Esso Research & Engrg. Co.) A lubricating composition comprising a major proportion of a mineral lubricating oil having a viscosity

(Continued on p. 413)

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C-5627, District Mgr. College, engrg.; age 30-50; 5 yrs. exp. mech. contracting, air cond., htg., plbg.; duties: estimate, negotiate, buy, sup't. & completely handle large mech. contracts in Fla.; some travel; sal. $7-9,000 plus profit sharing; loc. Fla.; emp. will pay fee.

Do the oldsters want jobs? ESPS wants to know!

Are there many or few retired engineers, or others past fifty, able and willing to take temporary jobs in engineering? Engineering Societies Personnel Service, the employment agency for the engineering societies, wants to know. The Board of Directors of ESPS has asked me to pose the question. Being on the retired list myself, both from the army and from active professional work, and having served as a member and chairman of the Board of ESPS, the question seems to me well worth trying to answer.

The current shortage of engineers and scientists is a well known fact. Continuous advertising in the newspapers of metropolitan areas, and the quarterly combing of our campuses, emphasize the need for young engineers and scientists. The supply does not begin to meet the demand for young men in these fields. Is the shortage confined to the young men, or does it include men in the older brackets in industry and government? Is it possible partially to meet today's need for engineers and scientists by temporary employment of men no longer young but willing and able to perform the required task? If such men are available and employers want them as temporary help, the task of trying to get employers and prospective employees together will be undertaken by ESPS.

It is realized, of course, that there are deterrents and complications in any attempt to employ older or retired engineers even temporarily on routine work. Some of the largest companies, whose engineer recruitment efforts are the most impressive, simply will not hire engineers or scientists over thirty-five. Their reasons are sound where permanency in an organization is envisaged. But temporary, day by day, or week by week, employment of men to help level off peak loads need not affect the retirement system of a company nor interfere with lines of promotion, apprenticeship jobs, and other factors vital to employment planned on a permanent basis.

From the viewpoint of the older prospective employee, the fifty-plus man, or the Social Security beneficiary of over sixty-five, there are deterrents too. These would tend to dampen the desire to take a "by the day" or week position as a temporary helper but not an integral part of a going organization. Granting the handicaps which exist from the viewpoint of both employer and prospective older employees, it still seems reasonable that some of the shortage of engineers could be met by greater use of the older members of our profession now unemployed or retired.

ESPS does not know how many of such potential employees are available. If you are an engineer or scientist over fifty, unemployed or retired, and if you are willing and able to take a temporary job, please tell ESPS. Send a brief letter to ESPS, 8 W. 40th St., N. Y. 18, N. Y. Just tell us your professional branch, your specialty, your age, and refer to this article. If the response is adequate in numbers, the ESPS Board will attempt to work out a plan to bring these older engineers and scientists together with the industries needing them.

It should be borne in mind, of course, that ESPS with offices in New York, Chicago, Detroit, and San Francisco continues ready to help any engineer or scientist of any age better his position or to obtain one. ESPS also continues to try to locate the particular engineer or scientist any specific employer may want. These have been the routine tasks of ESPS for more than 25 years. The proposal discussed here contemplates a special kind of placement from a yet unknown number of "prospects" fifty-plus in years who still desire to help themselves and their profession in the work of the nation.

W. N. Carey, Sec'y Emeritus, ASCE

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Current Literature

Shell-Mold Lubricants. Silicones which have proven particularly effective as release agents in shell-mold manufacture are described in the new edition of the 8-page illustrated booklet, "Union Carbide Silicones for the Shell-Molding Process." (Union Carbide & Carbon Corp., 30 E. 42nd St., N. Y. 17, N. Y.)

Dual Recording Titrometer. Bulletin 640-B describes the Precision-Dow Dual Recordomatic Titrometer. In addition to the applications of the unit, this illustrated bulletin discusses such features as wide range, automatic plotting of titration curve and control of titrant feed rate, simplified operation and sturdy construction. (Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill.)

Service Instruction Sheet for Type P Lubricators. Cyclic-type automatic lubricators, driven by the machine they lubricate, are described in a new 2-page service instruction sheet. Designated Type P, this rotary-drive lubricator is a piston pump type which is driven through built-in reduction gears by the machine it services, or by a small motor, and is adaptable to a wide range of metalworking machinery, printing presses, packaging machinery, machine tools, and a variety of special machinery. The instruction sheet discusses such items as operation, "starting a new machine," maintenance, and service. A detailed schematic drawing illustrates the operation and components of the lubricator. (Bijur Lubricating Corp., 151 W. Passaic St., Rochelle Park. N. J.)

Master Lubrication Handbook. Combined in one new loose-leaf book is all of the information contained in Check-Chart's renowned Automotive Lubrication, Truck, and Tractor Guides. Invaluable as a tool for oil company management and marketing executives, as well as division office personnel, the 1956 edition (the first section of which has just been published) will contain over 300 pages of lubrication charts and tabular data, including special Service Instructions. Individual sections are devoted to the provision of detailed information for U. S. and European Passenger Car, Truck, and Farm Tractor classifications, in addition to a general grouping which comprises School Bus, Motor Coach, Outboard Motor, Motorcycle, and Aircraft lubricant recommendations and capacities. Material is revised throughout the year through the medium of the company's Service Bulletin. (The Chek-Chart Corp., Sales Dept., 33 E. Congress Pkwy., Chicago 5, Ill.)

Corrosion-Resistant Piping and Fittings. A new 12-page catalog illustrates and describes the American Agile line of corrosion-resistant polyethylene and polyvinyl chloride pipe, tubing, ducting, valves, and fittings for industrial applications. Information contained for the first time includes a summary of Agile pipe materials in comprehensive form, a fuller explanation of fabricated pipe fittings, details on larger dimensions of cast pipe, properties of Agile pipe materials, and a complete listing of available literature offered by the company. (American Agile Corp., P. O. Box 168, Bedford, Ohio.)

"1955 Book of ASTM Standards (Part V)." Part V (of seven parts, and available separately at $11.00), dealing with Fuels, Petroleum, Aromatic Hydrocarbons, and Engine Antifreezes, contains 1,496 pages with 242 standards, 117 of which are new or have been revised since 1952. The following groups of subjects are included: Coal (classification, sampling, tests, screen analysis, size, dustiness, etc.); Petroleum (fuel oils, gasoline, diesel fuels, Stoddard Solvent; tests); Aromatic Hydrocarbons (benzene, naphtha, toluene, xylene; tests); Coke, Antifreezes, Gaseous Fuels, General Testing Methods. (American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.)

"The Acheson 'dag' Disperser," a new 4-page bulletin, is being published periodically to show what industry and research are doing with 'dag' colloidal dispersions. Applications relate to such various fields as metalworking, product engineering, ceramics, electronics, maintenance, and lubrication. (Acheson Colloids Co., Port Huron, Mich.)

"Engineering Handbook," No. 525, contains charts, illustrations, graphs, and all engineering data in the development of the "O" ring seal design; information on internal and external grooves, gland finishes, chamfers, selection of gland, piston rod, and cylinder materials and lubrication. Special sections of the handbook deal with silicone rubber products, custom molding, tables of decimal equivalents, temperature conversion table, circumference and area of circles. (Plastic & Rubber Products Co., 2100 Hyde Park Blvd., Los Angeles 47, Calif.)

Heavy-Duty Material Handling Pumps. Bulletin PP-56 features the new M & E material handling pumps for high volume, continuous operation primarily on maintenance painting, production finishing and coating applications. Units are readily adaptable to a wider range of general purpose and high speed production needs. (M & E Manufacturing Co., Dept. P-395, 2571 Winthrop Ave., Indianapolis 7, Ind.)

Drum Handling Equipment. A 4-page folder published by the Morse Manufacturing Company describes the firm's complete line of manual and motorized drum handling equipment. In addition to the company's rugged drum cradles, lifting hooks, hand trucks and tipping levers, the folder describes their portable drum rota-

tor which can be used anywhere in the plant to rotate a wide range of container sizes up to 500 pounds at any of three different speeds. (Morse Mfg. Co., 727 Manlius St., East Syracuse 1, N. Y.)

Lubrication Spray Equipment. A new 8-page brochure, Bulletin No. 60-A, provides complete information on Farval "Spray Lubrication Systems" for open gearing and slide surfaces. The 3-color, illustrated booklet offers descriptions of manual and automatic systems and component equipment with schematic layouts as well as actual application views. (The Farval Corp., 3249 E. 80th St., Cleveland 4, Ohio.)

"Precision Radial Roller Bearings," a new 56-page catalog-manual, combines the latest research data of Rollway engineers with current standards of Roller Bearing Engineers' Committee. In addition to comprehensive tabular information on radial static and dynamic capacities, the handbook also introduces for the first time the thrust capacities recently computed for Rollway's complete line of maximum type, precision radial roller bearings. Application data thoroughly covers load ratings, radial internal clearances, temperature allowances, provision for float, alignments, seals, lubrication. Bearing data is supplemented by engineering formulae, graphs, and drawings of representative installations. Tables also include limits for shaft diameters and housing bores to obtain proper fit of inner and outer races under various operating conditions. (Rollway Bearing Co., Inc., 541 Seymour St., Syracuse, N. Y.)

ASTE Reference Books. Future publication of three more important reference books has been announced by the American Society of Tool Engineers. "Machining with Carbides & Oxides" will combine the latest data on oxide (ceramic) tools with a thorough presentation of available information on carbide tooling and operations. "Jig & Fixture Design" will be written as

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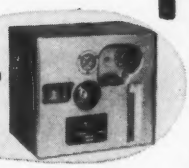
Y3400-6S	200
Y3400-8S	300



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the next logical step to follow the recently-published "Die Design Handbook" in equipping the tool engineer with reference material to supplement the technical knowledge his job requires. "Planning & Tooling for Powder Metal Parts" will encompass the practical data needed in design and production of powdered metal parts. The compilation of these books has already begun, and contributors who would like to submit manuscripts or engineering data to be considered for inclusion are encouraged to write: ASTE Books Dept., 10700 Puritan Ave., Detroit 38, Mich.

Teflon as a Metal Lubricant & Preservative. Highly successful use of Teflon (polytetrafluoroethylene resin) for lubricating and preserving a wide variety of military equipment is described in a Navy report available to industry through the Office of Technical Services, U. S. Dept. of Commerce. Applied as a thin film to hard substances, Teflon produces a dry, chemically-resistant all-weather lubricant. Its preservative qualities are described as remarkable by the Naval Research Lab. which pioneered use of the coating. The report summarizes experimental work and field tests on a number of applications of Teflon to guns and ammunition, submarines, aircraft, and other equipment. An appendix contains a number of essential techniques developed by NRL which insure minimum friction, maximum durability, good adhesion, and good corrosion-prevention properties. The report, PB-121161 "Thin Films of Polytetrafluoroethylene Resin (Teflon) as Lubricants and Preservative Coatings for Metals," V. G. Fritz-Simmons & W. A. Zisman, NRL, June 1956, may be ordered from OTS, U. S. Dept. of Commerce, Washington 25, D. C.; 32 pages, price $1.

Rust Preventive Book. A new 16-page book explaining how to solve the problems of rust with Valvoline tectyl rust preventives and rust removers has been made available. Chapters are devoted to: The Problem of Rust; Cleaning the Product; Materials in Corrosion Preventives; and, How to Choose a Rust Preventive. Inserted in a convenient pocket on the back cover are five comparison charts on Valvoline rust preventives, three giving pertinent data on U. S. Government approved packaging and preservatives, and two on industrial rust preventives. Each comparison chart gives the following information: nature of coating and description; film thickness in inches; approximate square foot coverage per gallon or per pound; approximate air drying time; application method and temperature; suggested method of removal; rust preventive description; and its particular use in industrial applications. Also included is a handy questionnaire for use in giving pertinent information for each particular industrial rust problem, which Valvoline engineers will then review and make specific recommendations. (Valvoline Oil Co., Tectyl Div., Freedom, Pa.)

Industrial Cleaning Compounds & Solvents. A new, 8-page bulletin discusses Brulin's complete line of industrial cleaning compounds and solvents. Illustrated with photographs, this bulletin gives detailed information and applications of chemicals for every industrial cleaning requirement. (Brulin & Co., Inc., 2939-45 Columbia Ave., Indianapolis 7, Ind.)

Lubricating Threaded Connectors. The lubrication of threaded connections is featured in the second issue of "Lubrication Newsletter" now available from Alpha Molykote. The lead article is a technical description of the causes of galling and seizing in threaded connections and power screws, and procedures for lubrication to practically eliminate these problems. Descriptive charts show coefficients of friction as calculated from both torque wrench measurements, and test data using a threaded assembly. Also included in the issue are application stories of

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SPECIALTY PRODUCTS CO., Jersey City, N. J.
SUNLAND REFINING CORP., Fresno, Calif.
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extreme-pressure lubrication on a steam turbine and on the loading screws of the world's largest universal testing machine. (The Alpha Molykote Corp., 65 Harvard Ave., Stamford, Conn.)

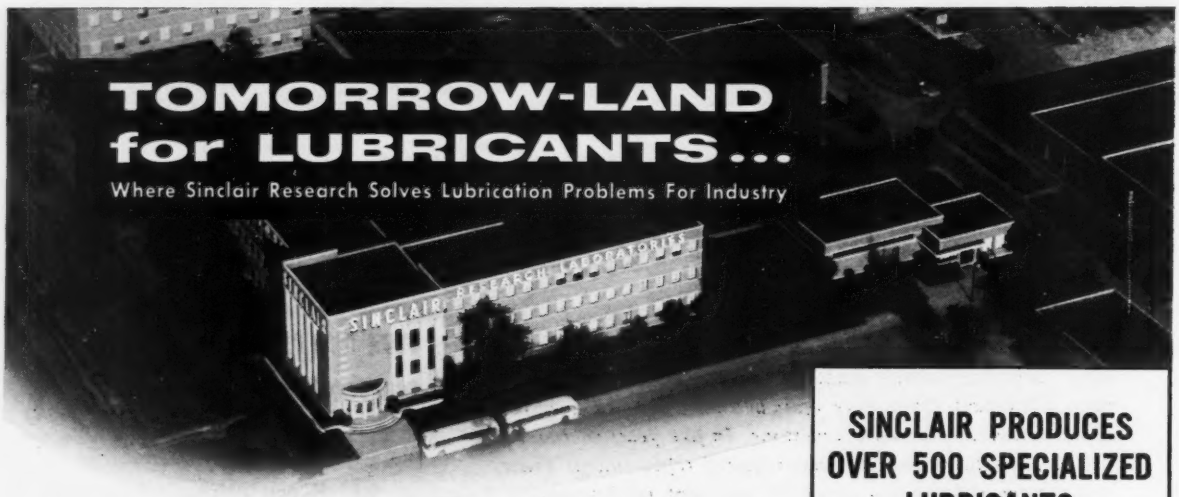
"The influence of Temperature on Petroleum Lubricating Grease" is the subject of a new Engineering Bulletin published by The Brooks Oil Co. Among other factors, the bulletin reviews the effects of temperature on consistency, apparent viscosity, adhesive and cohesive properties, and flow characteristics. (The Brooks Oil Co., Executive Sales Office, 934 Ridge Ave., Pittsburgh 12, Pa.)

"Power Lubrication Systems," a new catalog just published, features up-to-the-minute details on the most recent developments in power lubrication systems. Complete information is given on new, power-operated centralized lubrication systems, including those recently adopted as optional factory-installed service accessories by leading manufacturers of automobiles, truck-trailers, and industrial machinery. The book covers description and functions of manual as well as both mechanical and electric automatic controls, together with photographs of the various types of installations, diagrammatic illustrations, and information on ordering. (Lincoln Engineering Co., 5743 Natural Bridge Ave., St. Louis 20, Mo.)

Distribution Systems. Distribution systems for all types of Bijur automatic lubricators are described and illustrated in a new 2-color, 12-page brochure, Bulletin 4A. The bulletin describes the detailed planning of all systems and their many applications to a wide range of machinery. Following a system from oil reservoir to lubrication point, the booklet tells how and where to obtain the best results from any system. Reservoirs, tubing, fittings, junctions and Meter-Units are discussed in separate sections of the bulletin. Other sections deal with such matters as analysis of oil distribution and how systems are engineered to provide the correct oil film to individual lubrication points. Twenty-five drawings and photographs illustrate components of the systems, schematic layouts of systems and actual installations. (Bijur Lubricating Corp., 151 W. Passaic St., Rochelle Park, N. J.)

Recent Sunoco Technical Bulletins. Bulletin 44, "Sunvis 700 Oils," tells how to clean sludge out of hydraulic and lubrication systems without shutting down machines. Bulletin 46 describes "Sun C-891T Grease" which is designed to stay put under the worst conditions of dirt, moisture, low speeds, and high loads. Bulletin 47 describes "Sun N-52X Grease," a stable, high-melt-point grease for bearings running at temperatures up to 250° F., or for sealed antifriction bearings used at normal temperatures. (Sun Oil Co., 1608 Walnut St., Philadelphia 3, Pa.)

Market Analysis. "Market Potentials," a specialized report analyzing the modern sales possi-



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bilities of automotive lubricants and service products, has been announced by Chek-Chart. With emphasis on the growth in lubrication product sales since 1941, the publication is of special interest to oil marketing division and district managers, supervisors, and salesmen. (The Chek-Chart Corp., 33 E. Congress Pkwy., Chicago 5, Ill.; price $1.50)

"Supervisors Safety Manual." Written by staff engineers of the National Safety Council's industrial department and carefully reviewed by safety experts from business, industry, and government, the recently published "Supervisors Safety Manual" provides foremen with a comprehensive guide to all phases of industrial safety. The manual can be used as a text for group training or self study, or as a reference work to solve most of the general safety problems encountered by the foreman in his work day. It includes material on the human side of safety, maintaining interest in accident prevention, first aid, protective equipment, housekeeping, materials handling, machine guarding, portable power tools, and fire prevention. Available to Council members at $3.25; double the price for non-members. (National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.)

(Patent Abstracts, from p. 405)

between 50 and 200 SSU at 210 F., about 0.1 to 0.5% by weight of fatty acid selected from the group consisting of stearic acid and mixtures of stearic acid and palmitic acid, about 0.02 to 0.2% by weight of a C_{16} aliphatic substituted succinic acid, about 0.3 to 1.0% by weight of tricresyl phosphate, and about 0.2 to 0.5% by weight of oxidation inhibitor selected from the group consisting of phenyl alpha naphthylamine, ditertiary butyl para cresol and mixtures thereof.

Mineral Oil Compositions Having Stabilized Low Pour Points, Patent No. 2,730,501 (F. P. Otto, assignor to Socony Mobil Oil Co., Inc.) A lubricating oil composition having a stabilized low pour point comprising a major proportion of a mineral lubricating oil and a minor proportion, sufficient to lower the pour point of said oil, of a reaction product selected from the group consisting of (a) the product prepared by (1) reacting 1 mol of phenol with a sufficient amount of a chlorinated paraffin wax, containing about 18% by weight of chlorine, to supply approximately 4 atomic weights of chlorine to the reaction, at a temperature of from about 65 C. to about 177 C., to form a wax-alkylated phenol product, (2) forming a benzoate ester of the said wax-alkylated phenol product and (3) treating the said benzoate ester with a solid absorbent selected from the group consisting of activated carbon, silica gel and a bead cracking catalyst of the silica-alumina type, for a period of from about ½ hour to about 5 hours, at a temperature of from about 50 C. to about 200 C., and (b) the product prepared by (1) reacting 1 mol of phenol with a sufficient amount of chlorinated paraffin wax, containing about 18% by weight of chlorine, to supply approximately 4 atomic weights of chlorine to the reaction, at a temperature of from about 65 C. to about 177 C., to form a wax-alkylated phenol product, (2) treating the wax-alkylated phenol product with a solid absorbent selected from the group consisting of activated carbon, silica gel and bead cracking catalyst of the silica-alumina type, for a period of from about ½ hour to about 5 hours, at a temperature of from about 50 C. to about 200 C. and (3) forming the benzoate ester of the treated wax-alkylated phenol product.

Method for Incorporating A Solid Lubricant Into a Porous Metallic Surface, Patent No. 2,731,360 (P. P. Love, assignor to The Glacier Metal Co., Ltd.) A method for incorporating a solid non-metallic lubricant into a receptive metal surface comprising removing air from the surface by the application of sub-atmospheric pressure, thereafter applying the solid non-metallic lubricant to the receptive surface in the form of a colloidal suspension in a vaporizable carrier liquid, raising the pressure to drive the suspension into said surface, evaporating the carrier liquid to leave the solid lubricant in the receptive surface, repeating this cycle of treatment until the receptive surface is substantially filled with the solid lubricant, and then burnishing the impregnated surface to compact the solid lubricant therein.

Cloud Point Reduction of Mineral White Oils, Patent No. 2,731,391 (L. Salzman, assignor to L. Sonneborn Sons, Inc.) Method for the reduction of the normally relatively high cloud point of a mineral white oil, the cloud point of which is due to the less than 1% of wax contained therein, which comprises intimately contacting such white oil with an adsorbent carrying dispersed there through urea, at least a portion of which is in adsorbed condition resulting from alcoholic urea solution contact, and recovering mineral white oil of lower cloud point, said urea-

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- ☐ . . . . . Metal-working fluids
- ☐ . . . . . Heat-transfer fluids
- ☐ . . . . . Grease components
- ☐ . . . . . Textile lubricants
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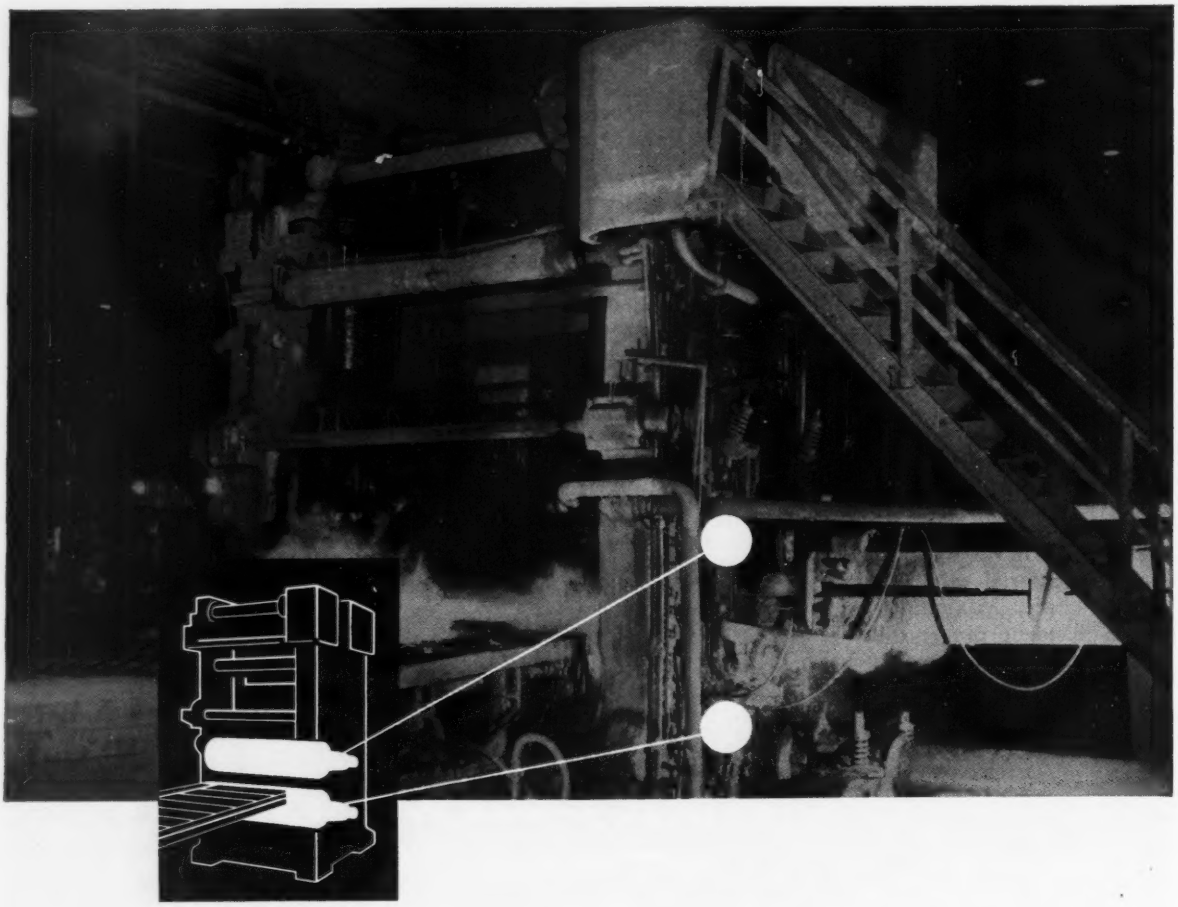
Lubricating roll necks is no easy job



Lubricating the roll necks of a steel mill calls for a lubricant that will resist high temperatures. The lubricant must also function in the presence of steam, water, mill scale and other abrasive materials. It has to cushion great shock loads and cling tenaciously to the bearings it protects. It must last a long time... and it must be economical in use.

Atlantic Lubricant 10 performs exceptionally well in this service. It is being used in a pressure system on the mill illustrated, at the Lukens Steel Company in Coatesville, Pa., for the lubrication of roll neck bearings, pinion and spindle bearings.

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carrying adsorbent being present in amount sufficient to lower said cloud point at least 15°F.

Tall Oil Pitch-Phosphorus Sulfide Reaction Product & Metallic Salts As Dispersants for Lubricating Oils, Patent No. 2,731,415 (E. O. Hook & L. C. Beegle, assignors to American Cyanamid Co.) A lubricating oil composition comprising a hydrocarbon lubricating oil having dissolved therein a detergent composition operative to assist in preventing the deposition of hard deposits due to sludge formation in the oil, said detergent composition comprising as its essential ingredient a neutralized reaction product resulting from chemically reacting phosphorus sesquisulfide with a mixture comprising a material containing a member of the group consisting of an unsaturated ester wax, a partially saponified unsaturated ester wax, and a completely saponified unsaturated ester wax and a material of the group consisting of refined tall oil pitch, partially saponified, refined tall oil pitch, and completely saponified refined tall oil pitch in the presence of a free-oxygen containing gas and at a temperature to promote such a reaction; and neutralizing the product of such reaction with a member of the group consisting of metal oxides and hydroxides.

Chemical Compounds, Methods of Making Same, and Lubricants Containing the Chemical Compounds, Patent No. 2,731,416 (O. L. Brandes & E. L. Humphrey, assignors to Gulf Research & Development Co.) A method of preparing a new compound, which comprises reacting a mixture consisting essentially of naphthenic acids and at least one phenol wherein at least one mol of the phenol is present for each mol of naphthenic acids in the presence of a Friedel-Crafts catalyst at an elevated temperature of at least 200°F. for a time sufficient to effect reaction between the naphthenic acids and the phenol, and thereafter reacting the resulting reaction product with an inorganic metal salt capable of forming the corresponding metal salt thereof.

Water Resistant Soda Base Grease, Patent No. 2,731,417 (L. F. King & W. C. Pattenden, assignors to Esso Research & Engrg. Co.) A lubricating grease composition prepared by thickening a major proportion of lubricating oil with a sodium soap of a high molecular weight fatty acid, admixing 0.1 to 10% by weight, based on the total composition, of sodium methyl siliconate of approximate formula $CH_3Si(OH)_2ONa$ in the presence of water, and heating the grease to a dehydrating temperature.

Hydraulic Transmission Fluid, Patent No. 2,731,418 (W. C. Howell, Jr. & J. I. Wasson, assignors to Esso Research & Engrg. Co.) A lubricant composition of high detergency and superior anti-

Speed Up ASSEMBLY LINE SPRAY APPLICATIONS

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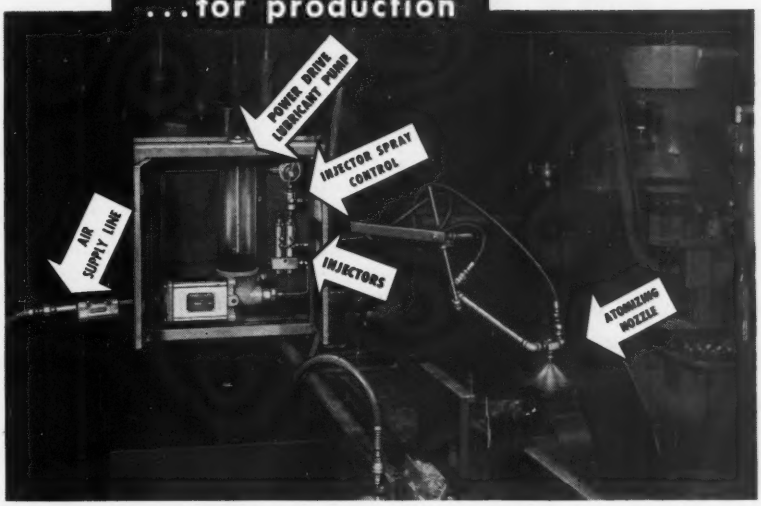
...for production



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friction properties, comprising a major proportion of a liquid lubricating oil base, 1 to 6% by weight, based on the total composition of an H_2S free alkaline earth metal salt of alkyl phenol sulfide as a detergent, 0.2 to 1% of fatty acid of the C_{12} to C_{22} range, and 0.2 to 0.5% of C_8 to C_{24} alkyl mercapto acetic acid.

Method for Determining the Deposit Forming Tendencies of Oils, Patent No. 2,732,285 (C. S. Lynch & E. B. Cyphers, assignors to Esso Research & Engrg. Co.) A method for testing the internal combustion engine deposit forming tendencies of mineral lubricants which comprises the steps of determining standard test conditions in which a mixture comprising a major amount of a mineral lubricant, and in the range of about 0.5 to 25% by weight, based on the lubricant, of an alpha, beta unsaturated ketone, and sulfuric acid are agitated together at a temperature in the range of about 200 to 450°F., in the presence of a deposit accumulator, forming a high molecular weight synthetic sludge, at least a portion of which tenaciously adheres to the surface of said accumulator, and determining the amount of said tenaciously adhering deposits on said accumulator, and then determining the comparative amount of said surface deposits formed when treating another lubricant under said standard test conditions.

Soluble Oils, Patent No. 2,732,345 (W. Kroenig, W. Hinsch, M. J. van der Zijden & W. F. Jense, assignors to Shell Development Co.) A one-phase soluble oil composition comprising a major amount of a mineral oil, a minor but effective corrosion inhibiting amount up to 10% of an oil-soluble nitrite, from about 1% to about 10% of a solutizer for the oil-insoluble nitrite, said solutizer being selected from the class of aliphatic diols and aliphatic ketols having from 4 to 10 carbon atoms and from 5% to 40% of an organic emulsifying agent having amphipathic properties and which forms oil-in-water emulsions.

Oil-in-Water Metalworking Lubricant, Patent No. 2,732,348 (W. F. Jense & C. B. Davies, assignors to Shell Development Co.) An improved oil-in-water metal working emulsion lubricant concentrate consisting essentially of a major amount of oil-in-water emulsion stabilized by addition thereto of a minor, but stabilizing amount, of an oil-soluble alkali metal petroleum sulfonate, and from a fraction of 1% up to 20% by weight of polyvinyl chloric polymer having an average molecular weight of from 40,000 to 100,000.

Sulfurized Hydrocarbon Lubricant Additive, Patent No. 2,732,346 (R. H. Jones & E. B. Cyphers, assignors to Esso Research & Engrg. Co.) A multifunctional lubricant additive obtained by reacting a substantially non-olefinic hydrocarbon feed stock, having an average molecular weight of at least 200 and containing at least about 20% by weight of alkyl aromatics, with elemental sulfur in an amount in the range of about 7 to 30% by weight based on the total reaction mixture, said reaction being carried out at a temperature in the range of about 400 to 500 F. for a time sufficient to form a product containing in the range of about 20 to 30% by weight of the originally added sulfur in chemically bound form.

Oil Composition for Air Filters, Patent No. 2,732,356 (C. E. Paxton, assignor to Esso Research & Engrg. Co.) A tacky oil composition having the property of adhering to fibrous filter media and the like and having a tacky surface characteristic such as to retain dust particles coming in contact therewith, comprising a mineral oil of lubricating grade and viscosity, a lithium soap in proportions of 0.25 to 0.5% by weight, based on the total composition, and 0.08 to 0.2% of a viscous tacky polyisobutylene of 25,000 to 125,000 molecular weight.

Mixed Alkaline Earth Metal Soap Grease Compositions, Patent No. 2,733,208 (E. O. Forster, assignor to Esso Research & Engrg. Co.) A lubricating grease composition which consists essentially of a lubricating oil base stock containing combined therein a grease forming amount of a mixture of calcium, barium, and strontium soaps of high molecular weight fatty acids, said mixture containing a molar ratio of calcium to barium to strontium soaps within the range of from 5:1:1 to 1:5:5.

Magnesium-Lithium-Sodium Grease Composition, Patent No. 2,733,209 (E. O. Forster, assignor to Esso Research & Engrg. Co.) A lubricating grease composition which consists essentially of a lubricating oil base stock containing combined therein a grease forming amount of a mixture of magnesium, lithium, and sodium soaps of high molecular weight fatty acids, said mixture containing a molar ratio of magnesium to lithium to sodium soaps of from 5:1:1 to 1:5:5.

(New Products, from p. 365)

chlorethylene, or perchlorethylene, requiring only minor adjustments of the thermostatic controls. The main body of the degreaser is constructed of galvanized steel with an outside coating of black Epodax solvent-impervious resin to reduce heat loss. A stainless steel coil is mounted as a condenser inside the chamber, and additional safety is pro-

vided by two thermostatic controls. The lower thermostat prevents breakdown of the chlorinated solvent due to thermal decomposition, and shuts off the machine when it requires draining; the upper thermostat is mounted above the stainless steel condensing coil as a safety device to prevent the solvent vapors from going out into the room in the event that the water supply fails. "Model 22" requires approximately 13 gallons of solvent for operation, and has a production capacity of approximately 350 lbs. of metal per hour. A wire mesh and expanded metal basket 18" in diameter, and a work rest (both galvanized) are also provided. (Tect, Inc., Cortland Ave. & Erie St., Dumont, N. J.)

Lubrication Testing Machine. A new lubricant-friction-wear testing machine, "Model LFW-1," has been developed primarily for testing bonded coatings, a lubrication technique which is finding broad use in all types of industrial applications; it can also be used for testing liquid lubricants. (The machine is the first in a series of lubrication testing machines being planned for industry by the company which has instituted a Testing Machine Division to develop and manufacture this equipment.) A relatively small table model, "Model LFW-1" not only maintains a high loading accuracy, but also indicates friction forces throughout the test. Another feature is a pre-setting device which automatically shuts off the machine after it reaches a pre-determined coefficient of friction. (The Alpha Molykote Corp., 65 Harvard Ave., Stamford, Conn.)

O-Ring Fitting. A new, straight-thread "O-Ring Locknut" fitting, available in all styles and in sizes from ⅛ to 2 inches, has been announced that is claimed to be leakproof, provide safer high-pressure connections, and be exceptionally easy to position. In addition, the new hydraulic fitting is interchangeable and meets all SAE and JIC standards. The "O-Ring Locknut" is already available in the company's Self-Flaring, No-Flare, and Flare type fittings. (Flodar Corp., 16911 St. Clair Ave., Cleveland 10, Ohio.)

Solid Film Lubricant. A new, air-dry solid film lubricant, "Lubri-Bond A," has been made available in a handy spray-on aerosol bomb. Excellent for lubricating parts operating at high speeds and extremely high loads, "Lubri-Bond A" operates in a temperature range from —300 to +500° F., and dries in 30 minutes. It can be used in conjunction with oils and greases where oil is necessary as a cooling agent, or it can be used without oils and greases when cooling is not a necessary function of the lubricant. (Electrofilm, Inc., P. O. Box 106, N. Hollywood, Calif.)

Low-Viscosity Lubricant. "Klingfast 115," a new low-viscosity lead-base gear and bearing lubricant for extreme-pressure applications, provides an extremely durable film which is difficult to remove either by gear pressure or gear speed. It is stable under normal service conditions, with no build-up in viscosity. The material is easily pumped at temperatures below freezing, and low viscosity permits easy starting after shutdown periods. The high polarity of the oil protects metal surfaces from corrosion. Specifications for "Klingfast 115" include the following: 115 SSU @ 210° F.; 1800 SSU @ 100° F.; Channel Point, —10° F.; Color, black; Minimum Timken, 43 lb. LAL, plus 30 minutes. (The Brooks Oil Co., 934 Ridge Ave., Pittsburgh 12, Pa.)

Micronic Full-Flow Filter. Newly-engineered filter housings, "Series QS," have been announced that are designed specifically for high-capacity diesel full-flow lube systems. Features of the new design are easy maintenance, effective micronic filtration, high flow rates, and lower cartridge replacement cost. The

(Continued on p. 420)

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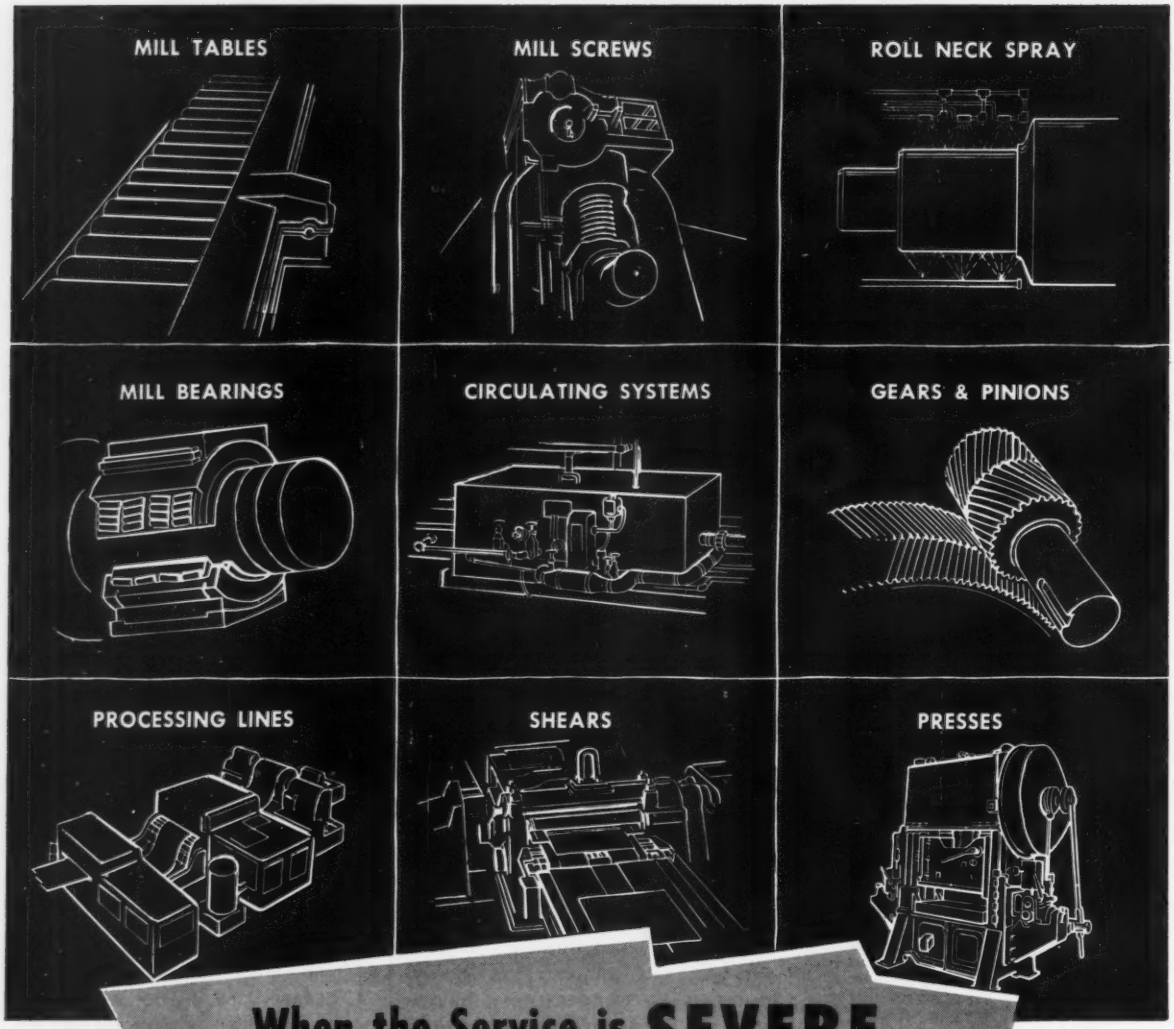

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Properties of Lubricants ..... C. W. Nichols, Jr., Socony Mobil Oil Co., Inc.
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Bendable Tubing. A unique line of bendable tubing, known as "Plica," is now being made and sold in the United States under exclusive rights acquired from Switzerland. Used for lubricating, coolant and other non-corrosive liquid lines, hot and cold air ducts, mechanical protection and insulation of pipes, flexible shaft casing, and for a wide variety of other uses, Plica tubing has a three-ply wall and can be made in almost any desired combination of ferrous and non-ferrous metals, fiber, paper, and other materials. It can be cut with a hacksaw or knife, bent by hand to stay bent, and fits all standard connectors; it has high wall strength, watertightness, and sharp bending radii. The size range is 3/8" thru 2" i.d. (The Flexaust Co., 100 Park Ave., New York 17, N. Y.)

Graphite Spray Lubricant. "Spray Graph," a new, instant-drying, long-lasting graphite lubricant is now available in 6 oz. spray containers, and can be successfully applied to both metallic and non-metallic surfaces. Effective lubrication is provided at temperatures ranging from —100 to 800° F. Oxidation, corrosion, and friction are greatly reduced, and "sticking" is prevented. The product is also distributed in bulk amounts to facilitate industrial use. It is being successfully used in the aircraft and automotive industries, photographic equipment, machine tools, office machines, precision instruments; paper, textile, baking and woodworking industries, and by the Armed Forces. The manufacturer will process production parts with "Spray Graph" in their Chicago plant according to customer specifications. (American Resin Corp., 3215 N. Sheffield Ave., Chicago 13, Ill.)

Powder-Metallurgy Compound. "Compo E," a new powder-metallurgy compound developed for the production of low-cost, oil-retaining bearings has been made available for general use. Composed of approximately equal parts of iron and bronze, it combines the economy and strength of iron with the anti-friction and long-life properties of bronze. While primarily intended as a low-cost, general-purpose bearing material, it can also be fabricated into sintered structural parts. Extensive field testing has proven it applicable where quiet operation is an essential. It has been used in fan motors, air conditioning motors and drives, record players, tape recorders, and home laundry equipment. (Bound Brook Oil-Less Bearing Co., Bound Brook, N. J.)

Silicone Defoamer. A new faster-acting, more stable silicone defoamer, Antifoam B, has been developed that is generally effective at concentrations in the range of 3 to 30 parts per million. Instantly dispersible in aqueous systems, it may be added "as is" without stirring or agitation. Because it has extremely small particle size, it also stays in suspension longer. Ideal for continuous processing, it will not oil out, plate out, settle, or precipitate in most applications. (Dow Corning Corp., Midland, Mich.)

O-Ring Compond for Use in Grease. A new 90 durometer synthetic material has been developed for molded seals in service

up to 300° F., with MIL-L-7870A grease for lubricating aircraft instruments, and MIL-L-6083 oil for preservative purposes in hydraulic equipment. The new material, designated Parker O-Ring Compound 49-091, is also recommended for use with MIL-L-7808A and MIL-L-5606 oil up to 250° F. (Parker Appliance Co., Rubber Products Div., 17325 Euclid Ave., Cleveland 12, Ohio.)

(Section News, from p. 363)

formance of Some Inorganic-Base Greases," by W. H. Peterson, Shell Development Co.

1957 Program Schedule: Jan. 10, "Lubrication in the Presence of Nuclear Radiation," by R. O. Bolt & J. G. Carroll, California Research Corp.; Feb. 14, "Lubrication Problems of Large Contractors," by R. Atkinson, Guy F. Atkinson Co.; Mar. 14, "Sleeve Bearings," by W. Phill, Federal-Mogul Corp.; Apr. 11, "Cutting Fluids," by L. H. Sudholz, Socony Mobil Oil Co.; May 9, "Aircraft Lubrication;" June, Annual Dinner Dance. (Submitted by G. H. Hommer, Sec'y.)

PHILADELPHIA, September meeting. L. T. White, Cities Service Oil Co., presented a paper entitled "How to Sell a Lubrication Program to Management." (Submitted by F. L. Heist, Sec'y.)

TWIN CITIES, September (Joint meeting with ASLE Duluth/Iron Range Section). J. Hoolihan, Industrial Lubricants Co., presented a paper entitled "Open Gears" at the evening session held in Duluth; the following morning, Reserve Iron Mining Co. served as host for a conducted tour of their new Taconite Plant in Silver Bay.

October. E. R. Booser (ASLE President), General Electric Co., presented a paper entitled "Atomic Power Plant Lubrication" — a survey of the problems with lubricants and lubrication in atomic power generating stations. (Submitted by C. H. Sweet, Sec'y.)

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Subject & Author Indexes for 1956

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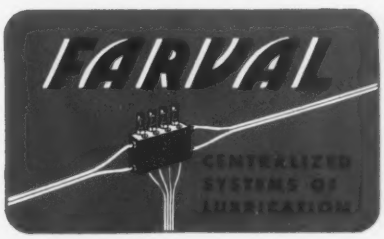

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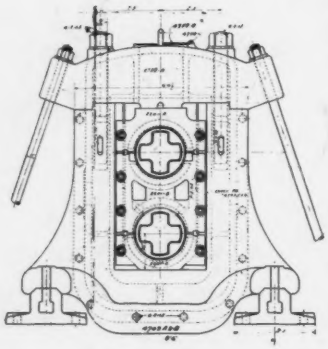

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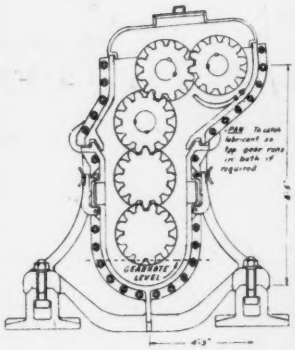

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